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UNIVERSITY OF ALBERTA

A STUDY OF INDUSTRIAL MAINTENANCE IN TANZANIA

BY

EMANUEL A. M. MJEMA ©

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE

IN

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DEPARTMENT OF MECHANICAL ENGINEERING

EDMONTON, ALBERTA

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DEDICATED TO MY LATE MOM
ELIZABETH NAVURI MSHESHI

ABSTRACT

Maintenance departments in many Tanzanian industries are in pathetic shapes. They lack skilled manpower and spare parts, have poor record-keeping, do ad-hoc execution of maintenance programs, and many unplanned maintenance activities. In general there are only haphazard and ineffective maintenance management systems. Maintenance personnel in Tanzanian industries assert that the major problems, which restrain their maintenance activities, are scarcity of spare parts and skilled manpower. A detailed analysis of the maintenance problems in Tanzanian industries has revealed that major problems are within the organization structures of the industries and management of maintenance activities.

Various maintenance techniques including: a) failure analysis and its application; b) breakdown maintenance; c) regular preventive maintenance; and, d) condition based maintenance are reviewed in this thesis. Advantages and disadvantages of each of these techniques for the Tanzanian situation are analyzed in-depth.

A maintenance model for Tanzanian industries, which can be used by small and medium size companies, is developed at the end of the thesis. The model is intended for a gradual implementation of preventive maintenance in Tanzanian industries.

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List of Abbreviations

AGTD -Alberta Gas Transmission Division

AISCO -Agricultural and Industrial Suppliers Company

BAT -British American Tobacco

Contr. Control

Depart. Department

FoE -Faculty of Engineering

FTC -Full Technician Certificate

IPI -Institute of Production Innovation

KMTMC -Kilimanjaro Machine Tools Manufacturing Company

LRA -Least Replaceable Assembly

Maint. Maintenance

MCP -Maintenance Control Program

MEIDA -Metal Engineering Industrial Development Association

MPG -Maintenance Planning Group

NDC -National Development Corporation

NVTC -National Vocational Training Centres

Prim. Primary

PWE -Problem report, Work request, Equipment maintenance record form

TCC -Tanzania Cigarette Company

TEXCO -Textile Companies

TIRDO -Tanzania Industrial Research and Development Organization

TISCO -Tanzania Industrial Studies and Consulting Organization

TLAI -Tanzania Leather and Associated Industries

TPCC -Tanzania Portland Cement Company

TSC -Tanzania Shoe Company

-Tanzania Saruji Company

Sch. -School

SPM -Southern Paper Mills

SUDECO Sugar Development Company

UDA -Usafiri Dar es Salaam

UDSM -University of Dar es Salaam

UFI -Ubungo Farm Implements Ltd, Dar es Salaam

UNIDO -United Nations Industrial Development Organization

ZZK -Zana Za Kilimo, Mbeya

1.0 Introduction:

Tanzanian industries are now facing challenges of reducing operational costs, improving productivity, and producing high quality products at reasonable costs. The new government policy of trade liberalization has prompted many industries to review their operational costs and productivity. The industries which were the only producer, and/or supplier of goods, are now facing stiff competition from imported goods which are of high quality and are selling at lower prices.

But many Tanzanian industries are operating at a very low capacity utilization; this situation makes the operational costs very high. A survey made by UNIDO (United Nations Industrial Development Organization) on third world countries reveals that, poor maintenance of installed equipment is a major factor contributing to a low capacity utilization.

This thesis analyzes the maintenance situation in Tanzanian industries. Using a questionnaire, a random sample of Tanzanian industries were given an opportunity to present their views on their maintenance problems. The sample size was 50 industries, which is about 10% of the Tanzanian industries employing at least 80 people. Except for a very few big industries, such as Southern Paper Mills (SPM), Tanzania Portland Cement Company (TPCC), and Kilimanjaro Machine Tools Manufacturing Company (KMTMC), the majority of

Tanzanian industries are in between the so-called 'small and medium' size industries. Being in the same category, it is assumed that all Tanzanian industries are basically facing similar problems. That assumption contributed to the decision of selecting a small sample size for analysis.

In addition, a maintenance system in a selected Canadian firm was analyzed. The aim was to compare a maintenance system in a developed country to a maintenance system in a developing country. The intention was to explore the limiting factors which hinder a full application of maintenance "theories" in a developing country like Tanzania. For the selected Canadian firm, direct interviews were conducted which appraised the maintenance system in a developed country. The main emphasis was on maintenance organization and management; the role of the maintenance department in a modern industry; and different techniques of carrying out maintenance activities in an industry.

Various maintenance systems are discussed. These include: breakdown maintenance; regular preventive maintenance; condition based maintenance; and maintenance prevention. The advantages and disadvantages of each of these maintenance techniques are analyzed. In addition, the author proposes procedures to execute each of the above maintenance techniques in industry.

Different condition based maintenance techniques are analyzed in-depth. The aim was to find inexpensive condition monitoring techniques which can be applied in small and medium size firms, the typical sizes of industries found in Tanzania. The potential use of different material testing techniques such as ultrasonic testing, acoustic emission, penetrant dye, temperature sensors, etc., in maintenance is not yet fully utilized, even in developed countries. An in-depth discussion on various equipment condition monitoring techniques, selection of equipment for condition monitoring, and selection of appropriate condition monitoring equipment is also included.

The common problems including those of: a) skilled manpower; b) spare parts; b) record keeping; c) maintenance organization; and, d) maintenance information systems; are analyzed in different perspective. In conclusion, a maintenance model suitable for the Tanzanian situation is designed. The model is for a small or medium size industry intending to implement a preventive maintenance program.

2.0 Problem Definition:

Tanzanian industries are faced by a number of problems, constraining the majority of them to only utilize 20 - 30% of their capacity [1]. This is a very low capacity utilization, especially when compared to that of developed countries. For example, in Canada the capacity utilization in manufacturing industry in 1981 was 81.5% [2]. "Industry" in this context, means any company with capital investment in equipment, such as manufacturing industry, transportation industry, processing industry, and assembling plant.

Problems identified as affecting capacity utilization include: lack of skilled labour; markets; lack of foreign currency (resulting in shortage of key inputs such as raw materials, spare parts, and other supporting materials); and effective production equipment. In addition to the factors mentioned above, poor maintenance of the equipment, which results in frequent breakdown, low availability, and low reliability of the equipment, is believed to be a major contributor to a low capacity utilization. Hence, one way of increasing capacity utilization is by improving the maintenance systems.

It has been estimated that, for a firm with an operating revenue of $20m per year, maintenance costs can be reduced up to 30% and production efficiency increased by 5% to 15% by an improved maintenance system [3]. This could result in a $1m to $3m per year increase in production with little additional cost and no additional production equipment. In the United Kingdom, maintenance costs £1.1 billion per year in the manufacturing industry alone. An improvement in maintenance could result in savings of about £200m to £250m per year through increased productivity and, a further saving of £300m through improved maintenance management and control [4].

In addition, a government sponsored survey in 1979 in the U.K. shows that the maintenance costs in engineering and metals industries is in average of 13.8% of the value of maintainable assets within a range of 7.9% to 23.7%. The same report shows that **downtime** is the major contributing factor in maintenance costs, due to lost production caused by both planned, and unplanned stoppages. Hence, one way of reducing maintenance costs is by improving the maintenance techniques and, hence, reducing the downtime. The typical downtime costs as indicated in major industries include: £1,500 per minute in automobile manufacture, £1,000 per hour in food processing and £1,000,000 per day in offshore oil production [5].

Unfortunately, financial information like the ones above are not readily available in many developing countries such as Tanzania. Nevertheless, an industrial survey made by UNIDO in developing countries shows that the installed equipment is poorly utilized. The UNIDO report indicates that considerable downtime of the equipment, caused by breakdowns and stoppages, contributes to the low capacity utilization [6]. In addition, the report shows that poor maintenance and repair causes huge economic losses (through low efficiency of the installed machinery), low quality of products, and higher production costs. So, from that report it is obvious that equipment maintenance is a very serious problem in developing countries.

The maintenance problem in Tanzania is aggravated by the fact that maintenance is not well understood. Maintenance is regarded merely as shop-floor activities, such as lubrication of machinery and repair of a machine or machine part when it breaks. The fact that less than 10% of the Tanzanian labour force is employed in modern industries (in 1974 it was only 3.3% of its total population) [7], a maintenance culture is not yet cultivated. Notably, even in Swahili the national language of Tanzania, there are not equivalent words for maintenance and related terms such as reliability; maintainability; and availability. Therefore, it is important to establish not only the maintenance management system, but also to create maintenance mindedness at all levels in the industry.

2.1. Background of Industrialization in Tanzania:

The background information on industrialization in Tanzania is intended to give information on how Tanzania acquired the modern type of industry. Also, the information will explain the origins of some of the problems, such as maintenance, that the industry is currently facing.

2.1.1 Pre - Independence Period 1884 - 1960:

The modern type of industry in Tanzania started after its colonization. In a pre-colonial period (before 1884 AD.) there existed "cottage" industries such as weaving, black-smithing, pottery and wood-working. Many of these crafts, however, did not survive the competition and regulations of colonization [8]. From the information available, the oldest manufacturing industry in Tanzania is the Tanganyika Cordage Company of Tanga [9]. This firm started to manufacture binder twine and export its products to the United Kingdom in early 1930. This industry, however, was closed down in 1935 because it could not sell its products in the UK due to 100% "ad valorem" duty imposed on binder twine imported from Tanzania. Table 2-1 shows that before 1946 there were only 101 establishments employing 10 or more persons. Out of these about 50% were involved in sisal decortication and cotton ginning.

2.1.2 Post Independence and Pre-Arusha Declaration 1961-1967:

From table 2-1 it is obvious that major industrial development in Tanzania took place during the post world war II period

Table 2-1: Tanzanian Industries

Historical review of manufacturing industry
(Establishment employing 10 or more)

Code ISIC	Industrial activity	Number of establish-ments 1965	Year of commencement of production pre-1946	1946-60	1960-65
20	Food manufacture ...	125	15	71	39
21	Beverage industries ..	11	4	3	4
22	Tobacco manufacture ...	3	1	2	-
23	Textiles *	158	50	66	42
24	Footwear and clothing	10	-	3	7
25	Wood except furniture	73	10	33	30
26	Furniture and fixtures	17	1	13	3
27-28	Paper, publishing	22	-	13	9
29	Leather products	8	4	3	1
30	Rubber products	5	-	2	3
31	Chemical products ...	18	-	11	7
33	Non-metallic products	9	1	5	3
34-35	Metals and products	19	1	5	14
36-36	Repair of machinery	12	1	6	5
38	Repair/transport eqpmt	73	11	43	19
39	Miscel. manufacture ..	6	2	-	4
	Total	569	101	279	189
	Percent	100	18	48	34

*Textiles include sisal decortication (110 establishments) and cotton ginning and cleaning (30 establishments). There was no textile establishment other than these two activities prior to 1961.

Source : United Republic of Tanzania,"Survey of Industries", 1965.

1946-60 and the post-independence period 1961-65. In 1965, 48% of the existing industries, were established during the post-war period, 34% were established during the post-independence period, and only 18% existed before 1946. So, the majority of modern industries in Tanzania are no more than 50 years old. This shows that modern industry is a relatively new phenomenon in Tanzanian society.

2.1.3 Arusha Declaration (1967):

The Arusha Declaration was a government/ruling party announcement, made on 5th February, 1967, declaring Tanzania a socialist state. As a result of the declaration, the government took control of major industrial companies in Tanzania. The government acquired the majority shares and votes through its company "National Development Corporation (NDC)". In a few cases, the foreign owners continued as minority shareholders, sometimes with a responsibility of supplying management.

2.1.3.1 Effects of Arusha Declaration on Tanzanian Industries:

The government nationalized the industries but it did not have the qualified staff to manage them. Perhaps the main assumption was that the existing management would continue under the new system. In some cases, the government successfully negotiated with the former owner of the industry, and that the later continued to provide management. A typical example is Tanzania Cigarette Company (TCC) which was formerly owned by British-American Tobacco (BAT). NDC agreed that it would pay for the 60% of the share of BAT in TCC in a 12 year period; and that BAT would provide TCC with management [10].

However, this was not the case for all other industries. For example, in the case of Tanzania Shoe Company (TSC), negotiation went on unsuccessfully between NDC and the Bata group (former owner of TSC) for fourteen months discussing compensation to Bata for the 60% of the shares taken over. In May 1968 the Nationalization Act was used to take over the TSC. All the expatriates seconded to the TSC left within a month after the nationalization [11].

There are many cases which are similar to TSC's case, in which there was no smooth transfer of industrial management from the previous owner of the industry and the new management. This affected the industries in both the short and long terms. For example, Tanganyika Packers could not sell its canned beef in the UK after nationalization of the company and exodus of the expatriates. Also, some suppliers of the machinery declined to recognize the new companies, and, thus, did not honour the contracts.

2.2 Summary:

1. Maintenance is a serious problem in many industries in Tanzania.

2. The modern type of industry in Tanzania is a relatively new phenomenon. Hence, some of the industrial problems are due to its newness to Tanzanian society.

3. Also, some of the maintenance problems originate from a sudden shift from a capitalist to a socialist mode of production; and the resultant exodus of experienced managers.

3.0 Analysis of Maintenance Problems:

The author sent 50 questionnaires to various Tanzanian industries in five regions (See the questionnaire on appendix 1), 40% of the questionnaires were returned. The industries that responded are mainly manufacturing and processing industries with an average of 592 employees and a range of 80 to 1500 employees. A general analysis of the questionnaire responses did not show any bias between small and big industries, and between processing and manufacturing industries. Hence, the sample can be considered as a representative of the maintenance problems for Tanzanian industries.

As shown in table 3-1, 50% of those who responded, did not include the financial information on their maintenance department. Some of them claim that the financial information is confidential, consequently it cannot be revealed to an unauthorised person. But, the majority of them commented that they do not keep records of their maintenance departments, and it is difficult for them to give a reasonable estimate of the costs. This is a very big problem since it is not possible to create a modern maintenance department without records. Record keeping is very important; without it, it is almost impossible to analyze the past performance and predict the future.

Table 3-1: Maintenance Costs/Annual Production

Annual Maintenance costs/Annual Production	Percent of replies.
Not available/No reply	50
1 - 3%	25
4 - 7%	5
8 - 11%	10
11 - 12%	10

For the remaining 50% who showed their maintenance costs, half of them spent about 1 to 3% of their annual production revenue in the maintenance department alone, which is a reasonable amount although it is still very big. But, 20% of the replies show that the maintenance costs are more than 8% of their annual production value. This is too much for just a single cost centre like maintenance.

When asked about the size of their maintenance departments, as apparent from table 3-2, 60% felt that the sizes of their maintenance departments are just right. This can be explained from psychological point of view; human being tends to be dedicated to whatever system exists to an extent that they don't want to change it. Hence, it is not surprising that the majority of the replies show that the sizes of their maintenance departments are satisfactory. However, the percentage of those who feel that their maintenance departments are too small is higher than those who feel that their maintenance departments are too large.

Table 3-2: Maintenance Departments' Size

Maintenance department is	Percent of replies
Too Large	15
Just Right	60
Too Small	25

The majority of the industries showed that they experience average failures each week. This question is difficult to quantify; average failure rate in one industry can be a high failure rate in another company. So the important point is the seriousness, and the consequence of the failures to an individual company. Table 3-3 snows that the percentage of those who feel that they have high failures each week, is smaller than those who feel that they experience low failures.

Table 3-3: Failures per Week

Failures experienced each week is:-	Percent of replies.
High	20
Average	45
Low	35

The problems affecting maintenance in Tanzania, as perceived by maintenance personnel are shown in table 3-4. From the table, it can be summarized that there are two major problems: lack of spare parts and lack of skilled personnel; the other problems can be related to one or the other of these two main categories.

Table 3-4: Maintenance Problems

The Problem	Percentage of those who replied
i. Lack of spare parts	75
ii. Lack of skilled personnel	70
iii. Lack of foreign currency to import spare parts	60
iv. Lack of raw material to manufacture spare parts	55
v. Lack of machine tools to manufacture spare parts	55
vi. Technology	55
vii Availability of working tools (spanner, puller,etc)	50
viii Old machinery and/or equipment	40
ix. Spare parts inventory	40
x. Lack of foundry	35
xi. Committed worker (motivated worker)	35
xii. Heat treatment facilities	30
xiii Training	30
xiv. Commitment of top management	30
xv. Delay in supply of spare parts	30
xvi. Politics	5

The problems which are related to spare parts include: lack of raw materials to manufacture spare parts; lack of foundry; lack of machine tools to manufacture spare parts, lack of heat treatment facilities; lack of foreign currency to purchase spare parts from abroad; and delay in supply of spare parts. The other problems which are related to the lack of skilled manpower or personnel in general include: technology; training; spare parts inventory; committed maintenance personnel; and commitment of top management.

3.1 Working Tools:

Availability of working tools is another problem which was mentioned by more than 50% of those who replied. Lack of tools such as pullers, spanners, jigs, etc., is mentioned by the majority of the personnel in maintenance departments. This problem is exacerbated by the fact that most of these working tools are stolen and sold by unfaithful employees. The take home income of the maintenance personnel, as is the case with the majority of Tanzanians, is very low; so they are likely to steal these working tools so as to subsidize their low income.

3.2 Top Management Support:

Other replies shows that the engineers are not enjoying the support from top management which is a vital tool, especially in introducing preventive maintenance. It shows that top managers emphasize production and fail to realize that high productivity is highly correlated with good maintenance management. One engineer commented that "...the indigenous technical personnel are not given full responsibility in maintaining their plants. The top management of the company has more faith in the so-called 'experts' who are not always as competent as the indigenous personnel. The low status given to indigenous engineers on the organization hierarchy demoralises them, consequently they don't fully apply their knowledge...". This quotation shows that the engineers are frustrated by the whole system to the extent of interfering with their work performance. This problem of having more faith in foreign experts by the managers was also addressed by the former Tanzanian president J.K. Nyerere. In his book, 'Freedom and Unity' he said,

> "...years of European domination had caused our people to have a grave doubts about their own abilities. This was no accident; any dominating group seeks to destroy the confidence of those they dominate because this helps them to maintain their position. The oppressors in Tanganyika [Before the union of the mainland Tanzania and the Zanzibar islands the former was called Tanganyika] were no exception. Indeed it can be argued that the biggest crime of oppression and foreign domination in Tanganyika and elsewhere, is the psychological effect it has on people who experience it...." [12].

The same idea is presented by the former president of the republic of Ghana, the late K. Nkrumah. In his book 'Revolutionary Path' [13], Nkrumah explains that colonials educated few African 'elite' in a way that they would accept, as part of the natural order of things, the colonial relationship. Also the 'elite' will defend the relationship in the name of 'justice', 'political liberty', and 'democracy'. Hence, it can be argued that, this treatment of the indigenous engineers by the managers might be due to lack of self-confidence, motivation and innovative consciousness among the management. The effects of colonization are also addressed by Diwan and Livingston, who state in their book, 'Alternative Development Strategies',

> " ...This exploitation extends to every aspect of colonized person: body, mind, output, land, resources, home,...,. The colonized is depicted as backward, coward, evil, lazy, sentimental, superstitious, thievish, unintelligent, virtual stupid, unscientific, ...," [14].

Hence, if the top management have the type of mind indicated by Diwan and Livingston, then it is obvious that they won't have faith on their maintenance engineers. As the result of it, the engineers feel unappreciated and demotivated. Motivation of workers is important in any sector of economy in order to make the workers perform their work efficiently. But, apparently, this is not the case in many Tanzanian industries.

3.3 Spare Parts Management:

Another area affected by poor management is in the inventory of spare parts. In many industries, spare parts are being purchased and managed by the purchasing department or store keeper. In most cases, these store people are not technical personnel and/or are not fully trained in store keeping and material handling. As a result, there is mishandling of spare parts and sometimes poor stock control. This increases the downtime of the equipment, especially during unplanned breakdown. Also, sometime spare parts are reported missing while they are available, or a lot of time is wasted in trying to identify and locate them. This is very frustrating especially when one is in urgent need of the spare part. Consequently, a repair problem which could take few minutes to rectify, takes hours or even days.

3.4 Old Machinery:

About 40% of the respondents showed that old machinery and/equipment causes problems to their maintenance work. This may be true for some cases, the machines are so old that it is very difficult to obtain their spare parts. The manufacturers of these machines no longer produce the same type of machines and don't support their outdated machinery with the proper spare parts. This problem might be caused by improper contracts during the procurement of the machinery. The machines were supplied without the necessary package to facilitate its smooth running. Information showing the average age of equipment in developing countries is not available.

However, some of the literature shows that, most of the machines in developing countries have shorter lives than do similar machines in developed countries, due to poor maintenance. In a UNIDO report it shows that, shorter equipment life is caused by poor maintenance and repair. The report says,

> "..In addition, poor maintenance and repair lead to deterioration and consequently shortened physical life of the installed equipment. This clearly is a significant waste of capital - the most scarce factor in developing countries..."[15].

Also, the UNIDO report shows that; in one country, 85% of tractors became idle and unserviceable only two years after they were imported because of lack of maintenance facilities and poor planning [16].

3.5 Politics:

Only 5% showed that politics affect their maintenance activities. This issue is not fully addressed, so it is not certain whether it meant the politics within the industrial systems or the politics on a nation-wide basis. In Tanzania, except for equipment which might be a potential hazard to the operators such as boilers and higher pressure equipment, a national policy guiding industrial maintenance policy does not exist. The ministry of labour and social welfare has a department of industrial inspectorate. This is a statutory board which is empowered to close down any industry, or part of the industry which is considered to be unsafe to the workers, neighbourhood or environment. However, research shows that, it is only in a very few industries that safety regulations are enforced [17]. Hence, even for the equipment which, by governmental regulations, is required to undergo constant inspection and maintenance, very little is done to keep it in a good running condition.

3.6 Availability of Skilled Labour:

Analysis on availability of skilled labour is shown in table 3-5. In the questionnaire, the industries were asked to indicate the number of their maintenance personnel and their qualifications. Although it can't be concluded that this represents the situation in all Tanzanian industries, it gives a real picture of the situation in many Tanzanian industries. It is disconcerting to note that 40% of those who replied did not have any engineer in their maintenance department and 10% did not have even a single technician. All of the industries had artisans, so it may be inferred that in the 10% without even a single technician, their maintenance programs are designed and executed by the artisans. From this information it is obvious that, these low level trained maintenance personnel would not be able to design and install an effective maintenance system.

Table 3-5: Maintenance Personnel

Qualification	Percentage of Industries which have					
	more than 3	only 3	only 2	only 1	0	total
Graduate engineer	5	20	15	20	40	100
Diploma engineer	0	5	0	30	65	100
Technician	55	0	15	20	10	100
Artisan	75	0	15	10	0	100
On-job trainee	55	20	0	15	10	100

3.7 Equipment Availability:

The question about the availability of the plant and/or equipment was not properly answered. It shows that the majority of those who replied did not understand the meaning of availability in maintenance terms. Consequently, the majority of the replies did not make any sense. This could be expected given that, as the above analysis (table 3-5) showed, about 40% of these industries did not have a graduate engineer, and 10% did not have even a technician. So as shown in from table 3-6, 50% of the replies did not make sense, or the question about availability was not answered. For the remaining 50% who replied to this question, 30% showed that the plant/equipment availability is in average of 70 - 80%.

From the maintenance problems which have already been discussed, and Msuya's report [1] which showed that Tanzanian industries are operating at 20-30% capacity utilization, and from table 3-1 which showed that 50% did not keep records of their maintenance activities, it is uncertain whether this is a true figure or if it is just an estimated figure without any supporting data. The 50% who did not reply to the question on equipment availability and those 15% who showed that the availability is between 40-50% are more in agreement with other information than those who showed that their equipment availability is between 70-80%.

Table 3-6: Equipment Availability

Availability	Percentage of those who replied
Not Clear (no reply)	50 %
40 - 50 %	15 %
51 - 60 %	0 %
61 - 70 %	5 %
71 - 80 %	30 %
Above 81 %	0 %

3.8 Type of Maintenance:

Very few industries showed that they have a planned maintenance management system. Most of the industries showed that they carry out breakdown maintenance. From table 3-7, it shows that 90% of those who replied have unplanned breakdown maintenance in most of their equipment. While 50% indicated that they have a preventive maintenance program for some of their equipment, they did not explain whether it is a planned preventive maintenance, or an impromptu preventive maintenance. But, 40% clearly commented that they have unplanned preventive maintenance, which includes oil changes, lubrications, cleaning etc. Only 5% showed that they have a predictive maintenance management program.

Table 3-7: Types of Maintenance

TYPE OF MAINTENANCE MENTIONED	PERCENTAGE OF REPLIES
1.Breakdown maintenance .... (Unplanned breakdown)	90
2.Unplanned preventive maintenance ...... (Lubrication, oil change,etc)	40
3.Preventive maintenance	50
4.Predictive maintenance	5

3.9 Other Problems (Not Mentioned in the Questionnaire):

3.9.1 Diversified Machinery:

Tanzanian industries have highly diversified range of machinery and equipment obtained from different manufacturers and different countries. For example, in Dar es Salaam city transit (UDA), there are buses from the U.K. (Leyland-Albion), West Germany (Mercedes-Benz), Hungary (Ikarus), and India (Tata). In most cases, the spare parts for these buses are not compatible. Hence, in order to keep the buses in a good running condition, it is necessary to keep a large stock of different kinds of spare parts. This is very expensive, especially taking into consideration that one has to import small quantities of these spare parts from different countries.

3.9.2 Maintenance Manuals:

Scarcity of maintenance manuals may also contribute to problems of maintenance management in Tanzania. As it has been discussed, Tanzanian industries have machinery from various countries all over the world. The suppliers of this machinery are reluctant to provide technical documents in user's language. This makes the few documents available difficult to understand, and consequently it is difficult to make an effective maintenance schedules as per the manufacturer's recommendations. Also, for the few available documents, the information given is not detailed enough to enable the maintenance personnel to run or service the machines and equipment in the best way.

3.9.3 Maintenance Management Systems:

Poor maintenance management systems may exacerbate the already mentioned maintenance problems. If the maintenance manager makes a poor forecast of his/her needs in the maintenance department, the consequence may be depletion of resources (such as spare parts, raw materials to manufacture spare parts, etc.) before the planned time elapses. Knowing about the red tape involved in any procurement needing foreign currency in Tanzania, a maintenance manager tries to make sure that he/she has a three year stock of spare parts. For example, to order a spare part might take the following procedure:

-Prepare spare parts requisition forecast	3 months
-Get an approval from the purchasing dept.	3 months
-Get an approval from the top management	3 months
-Send requisition to ministry of industries	1 month
-Get an approval from the ministry of industries	8 months
-Send the requisition to the central bank	1 month
-Get an approval from the central bank	8 months
-Send a purchase order to Europe	1 month
-Get the spares-lag period if from Eastern Europe	6 months
Total elapsed time	**34 months**

A 100% perfect forecast for spare parts required for a three year period is almost impossible. Even if the maintenance engineer is very competent in his/her work, normally there will occur unexpected breakdowns which will need prompt attention and spare parts. If the spare part is not available in the store, an efficient mechanism is needed to import the required spare part in the shortest possible period of time. However, this red tape is beyond the industrial level. The whole problem needs a dramatic change in foreign currency policy at the national level.

For spare parts which can be manufactured within the industry, the tendency is to manufacture the spare part after failure occurs. This increases the downtime as the part has to be taken to engineering, drawings prepared, and then sent to a workshop to be manufactured. A good tendency would be to make a list of all parts which are likely to fail, then manufacture and stock the spare parts for the time of need.

3.9.4 Maintenance Information Systems:

Poor flow of information may cause a longer waiting time and, thus, increase the downtime. How failure is reported to a repair man, who makes the decision to repair, and how soon the repair resources are available is critical in an unplanned breakdown. Also, important is the relationship between the production department and the maintenance department. The following question may be asked so as to explore the relationship between these two departments: Is it possible for an operator to report a failure directly to the maintenance department, or the reporting has to follow a formal channel of reporting through the foreman of the production department to the foreman of the maintenance department? In many Tanzanian industries the long waiting time might be caused by poor communication between the departments concerned.

Also, in many industries the operators do not have even the slightest technical knowledge of the machines they operate. Consequently, the failure report is not submitted in technical terms and is ambiguous. If the right man was on the failure spot, troubleshooting could start immediately, and proper failure information be reported. This could reduce the repair task since, when the problem is clearly understood, the only task would be to prepare a task force to arrest the problem. An ideal situation would to use operators who have a technical know how of the equipment they operate.

3.9.5 The Operator's Skill:

If the skill of the operators is low, he/she may cause problems to a machine. Sometimes the failure of the machine is caused by the operators due to misuse of the machine, and/or sometimes the operators do not report the problem as soon as an initial sign of equipment failure is apparent. If the operators were able to report problems at their early stage, proper action could be taken before total failure took place. In some industries, in order to increase productivity, they introduced a 'piece-work' system. Workers were given a target production, which when reached, allowed the workers to either take a day off or produce more and get a bonus. This resulted in workers over-speeding the machines. A high running speed can wear out a machine in a short time, and thus cause unexpected failure. An optimum running speed of the machine should be set so as to avoid the problem of over-speeding. In some big companies like Nova Corporation of Alberta (See chapter 4), the maintenance group sets an operational baseline for the equipment which the operators are not supposed to exceed.

3.9.6 Temporary Solutions Being Permanent:

Another problem is the tendency of using temporary solutions as permanent solutions. For example, due to the scarcity of spare parts, sometimes the maintenance personnel use temporary measures to arrest a problem, such as using different material to manufacture spare parts or using a totally different spare part (eg. using a rubber band instead of a belt). This different material might be of lower quality than the genuine spare part, but the tendency is to use this temporary spare part until the next breakdown takes place. This tendency increases the machinery breakdown and, hence, reduces the machinery reliability. In addition, if it is a totally different spare part, sometimes it may cause machinery malfunction.

Another aspect of using a temporary solution as a permanent solution is when a broken part is replaced by a similar part without doing failure analysis. For example, when a shaft breaks the proper solution is not just to replace the shaft with a new shaft. Shaft breakage may be caused by a number of factors such as misalignment, or excessive vibration, so replacement of the shaft without finding the real cause of the breakage is not the solution. Failure analysis helps to carry out the proper maintenance action. Failure analysis is fully discussed in chapter 5 of this thesis.

3.9.7 Cannibalization of Equipment:

Cannibalization of equipment is a problem which is rampant especially in the transportation industry. Due to scarcity of spare parts, some industries take part(s) of some machines to secure the needed spare parts for other machine(s). This is a destruction of capital. To revive cannibalized equipment will need a lot of new investment money. This problem is highly visible at the UDA workshop at Ubungo Dar es Salaam, in which more than half of the Ikarus bus fleet was cannibalized to revive the other few running Ikarus buses. This tendency affects not only the cannibalized equipment, but also the quality of maintenance to the other equipment by using second hand spare parts. The objective of maintenance is to renew the machine part(s), if a second hand spare part(s) is used, this objective is not met.

3.9.8 Proper Technology for Tanzanian Environment:

The work environment can contribute to frequent machine failure. For example, the climate of Dar es Salaam city is characterized by high temperature and high humidity throughout the year. Consequently, the majority of the industries' buildings have big openings so as to allow a natural circulation of air. This type of building exposes the machines to dust, which might contain corrosive substances thus accelerating the problem of breakdown. In other types of buildings which are closed and air conditioned, there is a problem of frequent breakdown of the air conditioning system. In this situation, the machines are exposed to high temperatures which might contribute to frequent breakdown. This problem of failure due to climatical condition, may be caused by a wrong decision during procurement. The designer of these machines did not take into consideration the dust, high temperature, and a high humid work environment which exists in many Tanzanian industries. It seems that, choosing the proper technology suitable for the Tanzanian environment is a big problem. Technical studies carried jointly by local experts and suppliers could result in modification or adaptation in design and /or material selection which would be more suitable for Tanzania.

The problem of proper technology is exacerbated if the technology is being financed by an external aid. In many cases the aid donors have made their own choice of technology and/or equipment which are not always the best for the receiver. Some of the machines are too modern for the user to do proper maintenance. This is the case for Mwanza Textile Mills and Southern Paper Mills in Mufindi. In these industries, the management has to hire external experts for maintenance of the machinery. Also, the spare parts of these machines are very expensive and, in most cases, must be imported. But the problem is not totally of the donor, although there are very few donors who will give money to purchase equipment anywhere else (untied aid). Part of the problem is the receiver. The receiver does not have to accept everything given to her; indeed, Tanzania should refuse the technologies which are not appropriate to her environment. Often the personnel responsible for making the decision to accept or refuse the aid, do not know whether the technology is suitable to Tanzania or not.

3.9.9 Lubricants:

Using unrecommended lubricants is another problem which has been identified in industries. This problem might be caused by an unavailability of the recommended lubricant. The effect of lubrication is not only the oily effect which stops rusting, but the more importantly, to introduce an oil film between two relative moving parts so as to reduce the wear (figure 3-1). This oil film separates the rolling element, hence reducing the rubbing effect. The oil film is affected by the viscosity of the lubricant used, and the type and amount of load carried by the rolling element. That is, different lubricants which have different viscosities do not produce the same effect when applied to the same equipment under the same load. So when using other lubricants than the recommended ones, it is important to analyze their characteristics so as to determine their suitability to the particular equipment.

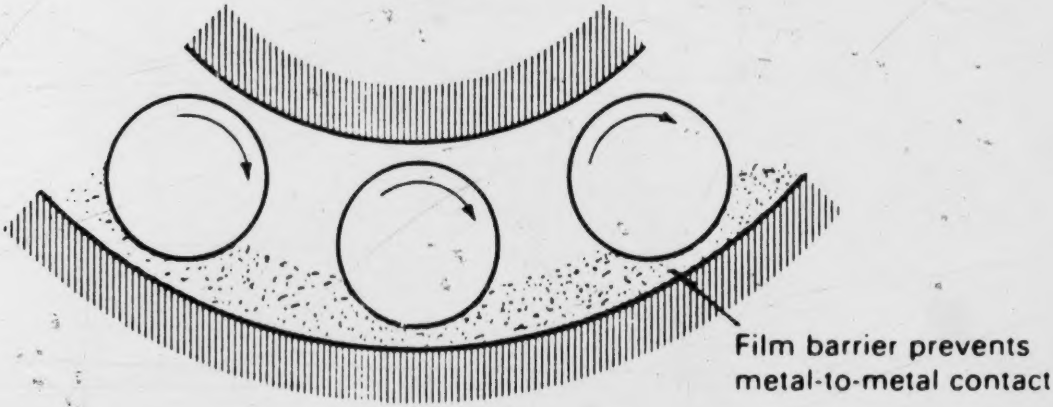


Figure 3-1: A film of Lubrication

3.9.10 Cleanliness:

In many Tanzanian industries, equipment cleanliness is not emphasized as a preventive maintenance action. It is common to see equipment covered by dust, dirty oil, and grease. The situation is worse in a machine shop, where metal filings are often found on almost every machine tool. The best way of dealing with this problem is to assign the cleaning responsibility to machine operators. Every operator must clean the equipment each time he/she uses it. Cleanliness should be emphasized in equipment which needs regular lubrication and greasing. Grease attracts and holds particles such as metal filings, dirt particles, etc., and so if the grease holes are not clean, the grease gun could force contaminants between the moving parts. This will scratch and accelerate the wear of the moving parts and therefore, should be avoided. This is one example of doing preventive maintenance in a wrong way; it is sometimes better not to lubricate at all than to lubricate dirty equipment.

3.10 Summary:

Maintenance is pervasive and serious problem in almost all Tanzanian industries. This analysis of the maintenance problems in Tanzanian industries shows that the maintenance problems are so diversified that it is very difficult to classify them into a few major groups. However, the following maintenance problems are more visible:

i) The problem of skilled manpower - there is a scarcity of engineers and qualified technicians to run the industries.

ii) The spare parts problem - there is a mismanagement of spare parts, lack of technology and equipment to manufacture the spare parts, and difficulty in spare parts procurement.

iii) Maintenance organization problem - it seems that there is a poor maintenance management system in many Tanzanian industries.

iv) Top management support - the analysis shows that top management either is ignorant of the importance of maintenance, or does not provide the necessary and/or adequate support to the maintenance department.

v) Lack of Maintenance Culture - maintenance is not well understood by the majority of Tanzanians.

vi) Appropriate technology - it seems that Tanzanians lack the necessary knowledge to choose the appropriate technology for their environment.

vii) Maintenance Support System - there is a lack of necessary facilities such as workshop, foundry, heat treatment facilities, etc. to support maintenance.

viii) Record keeping - the majority of the industries confessed that they don't keep records of the maintenance activities.

4.0 Canadian Maintenance Industry - A Case Study:

4.1 The Company:

An industry selected for case study among the Canadian companies is AGTD (Alberta Gas Transmission Division), a division of Nova Corporation of Alberta. Nova Corporation of Alberta, hereinafter referred to as Nova, is a major shareholder-owned company which operates internationally with its world headquarters in Calgary, Alberta. Nova is among the largest publicly owned companies in Canada, its business includes petroleum, pipelines and gas marketing, petrochemicals, related engineering consulting, and manufacturing.

Nova owns the following principal subsidiary or division companies: Alberta Gas Transmission Division (AGTD) with head office in Edmonton, Alberta; Grove Italia S.P.A with head office in Voghera, Italy; Novacor Chemicals Ltd. with head office in Calgary, Alberta; Novacorp International Consulting Inc. with head office in Calgary, Alberta; Novalta Resources Ltd. with head office in Calgary, Alberta; Polysar Limited - Basic Petrochemical Division with head office in Sarnia, Ontario; and Polysar Limited - Polymer Division with head office in Toronto, Ontario. Also the following companies are affiliated with Nova: Foothills Pipe Lines (Yukon) Ltd. - head office in Calgary, Alberta; Husky Oil Ltd. - head office in Calgary, Alberta; Pan-Alberta Gas Ltd. - head office in

Calgary, Alberta; and Trans Quebec & Maritimes Pipeline Inc. with head office in Montreal, Quebec.

In 1988 Nova sales were $3,941 million ($ in this report will refer to Canadian $ unless otherwise stated), with an operating income of $978 million, and a net income of $424 million. Total assets at the end of 1988 was $8,242 million which included current assets of $1,461 million, investment and other assets of $1,082 million, and fixed assets (plant, property and equipment less accumulated depreciation and depletion) of $5,699 million. The total number of employees of Nova (subsidiaries and affiliates included) in 1988 was about 13,000 in Canada, US, Europe, and in Pacific Rim Countries (Source: Nova 1988 Annual Report).

AGTD (Alberta Gas Transmission Division) is a gas transmission company, 100% owned by Nova Corporation of Alberta. The AGTD maintenance department is among the most modern in Canadian industry. The maintenance department in AGTD uses a combination of regular preventive maintenance, condition based maintenance, and improvement maintenance in their equipment. Failure analysis is an effective tool used by the Maintenance Planning Group (MPG) on deciding the type of maintenance to be done on equipment, and in analyzing the effectiveness of the maintenance programs. A senior officer in MPG commented that, it is almost impossible to operate a modern maintenance department without doing failure analysis. With the utilization of computers, it is easier for MPG to make failure, financial, and other maintenance related data analysis.

AGTD is currently developing an in-house maintenance software package known as MCP (Maintenance Control Program) which is a mainframe package, but another source [18] indicates that MCP-Mainframe software will be translated into MCP-PC, a version for personal computers (PCs) for commercialization purposes. Computerization of maintenance activities in Nova-AGTD, which started as early as 1981 by computerizing their data base, has tremendously reduced the maintenance costs and increased the effectiveness of the maintenance programs. The software is being used to keep track of all equipment, any maintenance activity done on the equipment, inspection data, condition information which is used for condition monitoring, report writing, and other activities such as spare parts inventories. Therefore, the Nova-AGTD's maintenance department can be taken as the 'state-of-the-art' maintenance department. The department will be used as a good example of a modern maintenance department.

4.2 Maintenance Organization:

Nova-AGTD's maintenance department has a Maintenance Planning Group (MPG), a centralized maintenance planning organ, which coordinates and supervises maintenance throughout Nova-AGTD. The objectives of MPG are:

i) To achieve required system availability (reduce downtime),

ii) To obtain required station /equipment reliability,

iii) To minimize maintenance and maintenance related costs, and

iv) To ensure the safety of NOVA resources (equipment and personnel).

In order to be able to accomplish the objectives of maintenance, it is important to figure out where to place the maintenance group in an organization structure. The position of a maintenance department in an organization structure of a company, determines the status of the department and, hence, its effectiveness. If the maintenance department is in an inferior position in an organization, then its activities also will be considered inferior to other activities in the company. The maintenance department should be given equal status to other departments in an organization.

The maintenance group can be parcelled out in various departmental groups so that each group is customized to the specific needs of the department, or the maintenance group can be a centralized organ to handle the total needs of the company. While each organization can make its own decision,

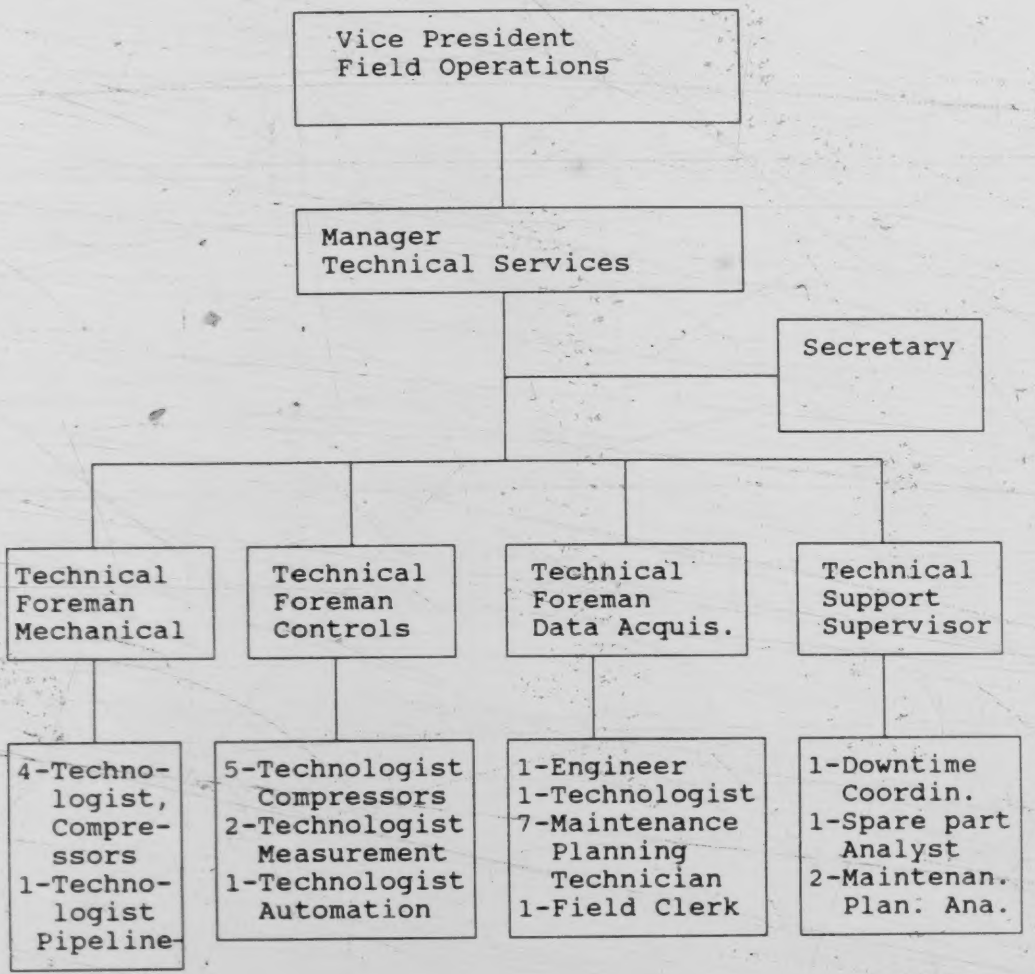

Vice President
Field Operations
Manager
Technical Services
Secretary
Technical Foreman Mechanical
Technical Foreman Controls
Technical Foreman Data Acquis.
Technical Support Supervisor
4-Technologist, Compressors
1-Technologist Pipeline
5-Technologist Compressors
2-Technologist Measurement
1-Technologist Automation
1-Engineer
1-Technologist
7-Maintenance Planning Technician
1-Field Clerk
1-Downtime Coordin.
1-Spare part Analyst
2-Maintenan. Plan. Ana.

Figure 4-1: Organization Structure - MPG

a centralized organization produces greater consistency when performing maintenance activities and avoids duplication of effort. In the case of AGTD, the decision made was to make MPG a centralized maintenance group. Although, the maintenance group has to be as close to the production group as possible, research shows [19] that, whenever maintenance is placed directly under the production group, maintenance suffers. Given that more emphasis will be placed on production activities than maintenance activities, it is important to create a maintenance department as a separate entity.

A maintenance group could fit within any other technical support group, in each case advantages and disadvantages of either choice should be analyzed so as to fit the needs of the firm concerned. An important point to be considered is the existence of a clear communication between the various departments, which will be affected by maintenance activities in one way or another.

The Maintenance Planning Group (MPG) is divided according to areas of responsibilities. The MPG's responsibilities are: developing, preparing, implementing, and monitoring of maintenance activities for mechanical systems, controls, pipeline, measurement, and electrical equipment within AGTD. To assume these responsibilities, MPG is divided into five main areas: mechanical; controls; measurement; data acquisition; and technical support. MPG is under the Technical service department which is directly under the Field Operation division led by a vice president.

The important thing to note in the organization of maintenance is the responsibility division of labour. The sections in MPG are divided according to their responsibilities, each section having its own function. Even for a small task, such as downtime, there is somebody who is responsible for coordination of the downtime and he/she becomes fully accountable for that type of task. In that situation everyone in the maintenance group knows his/her responsibility, which reduces the ambiguity and the necessity of having supervisors to parcel activities each morning. The only task remaining is to coordinate the activities of each section, and to take care of the absentees.

4.3 MPG Responsibilities:

MPG will help to show a typical example of the well-defined responsibilities of a maintenance department. In many Tanzanian firms, it is not clear as to what are the responsibilities of a maintenance department and what are the responsibilities of the operation/production department. The main responsibilities of MPG are:

i) Gathering, auditing, monitoring, and maintaining an accurate data base for all equipment within Nova-AGTD. The data include fixed information of equipment (known as "name plate"), historical information, inspection task, and operating information. Using a computer program -MCP

(Maintenance Control Program - already introduced in section 4.1), it is possible to store, retrieve, and manipulate as much information as necessary.

ii) MPG uses the MCP data base for analysis and reporting of maintenance activities throughout Nova-AGTD with the aim of: a) identifying areas of high maintenance activities and costs; b) making recommendations; and c) providing justification on equipment modification or replacement. MPG prepares, monitors, and analyzes inspection programs for all equipment. This involves a complete review of history, spare parts requirement, equipment operating condition, manufacturer's recommendation, and service bulletins.

iii) The maintenance department is responsible for arresting unplanned maintenance and related problems, such as deterioration in condition, performance, and efficiency by: delivering incident reports; monitoring of incoming PWE (Problem report, Work request, Equipment maintenance record) forms; analysis of compressor health monitoring data; review of unit and station log sheets; and analysis of gas control activity log-book. MPG provides technical expertise; maintenance cost summaries; operating data; project justification to other departments to supports compressor modernization programs; measurement modernization program; new equipment selection; unit upgrades; major equipment modifications; and special project planning.

iv) MPG liaison with equipment manufacturers and other users for the purpose of exchanging technical and operating information. The information is used to update and enhance existing equipment maintenance programs, and in the development of new programs to avert potential problems or catastrophic failures. Also, MPG assists with the investigations into major failures and/or incidents. MPG reviews equipment condition during manufacturers' overhauls, internal overhauls, and on-site inspections to determine maintenance program effectiveness, and extent of repair required. In addition, MPG assists in evaluating future component life, time until next overhaul, and future inspection requirements. When necessary, MPG initiates, reviews, and ensures implementation of Nova service bulletins relating to proposed modifications and/or deviations from normal operating parameters or procedures. MPG acts as chairman of modification meetings so as to ensure that: a) the modifications are applicable to various locations; b) there is consistency of maintenance throughout the system; c) completion of modifications is tracked; and d) manuals are updated and printed.

v) MPG is responsible for maintaining spare parts information, by reviewing and updating spare parts' descriptions and stock levels. MPG establishes inspection and emergency spare parts requirement for existing, modified, and new equipment. The group provides technical and spare parts support to maintenance personnel during scheduled/unscheduled outages and emergency repairs.

vi) The maintenance department is not only responsible for maintaining the equipment, but also to ensure that it is safe to work with. MPG interfaces with the boilers branch, the electrical protection branch, insurance underwriters, environment affairs, and other regulatory bodies to ensure compliance with safety standards and regulations.

vii) MPG reviews system operating statistics to determine inspection requirements. The group coordinates and schedules downtime for maintenance and modification requirements in cooperation with all the groups affected by such outages. MPG is responsible for performing a wide variety of tests on equipment within AGTD for the purpose of establishing operational baselines, new unit acceptance, troubleshooting assistance, and suitable test data which meets the needs of various engineering and operational groups. These tests include: a) performance and vibration tests on turbine compressor units; b) performance and vibration testing on reciprocating units; c) establishment of acceptable surge control lines for centrifugal compressors; and d) other specialized testing such as modal, pulsation, strain gauge, and sound level testing.

viii) Giving technical support to other departments is another responsibility of a maintenance department. MPG is responsible for supporting Novacorp International Consulting, Inc. (another company owned by Nova) through presentations, training, technical skills and equipment testing. Lastly, MPG is responsible for supporting field operations and other departments in the area of technical training in: a) health monitoring, b) compressor schools, and c) measurement schools.

An important lesson to learn from the MPG's responsibilities is that MPG is not only responsible for maintaining the existing equipment, but also for the selection of new equipment and training of the personnel. MPG provides data for evaluating the acceptability of new unit within the existing operating system. This responsibility of selecting new equipment is not found as a responsibility of maintenance departments in Tanzanian industries. It seems reasonable to let the maintenance personnel recommend certain types of equipment from a maintenance point of view and production personnel set their own recommendations from a production point of view.

MPG also acts as a liaison officer for Nova-AGTD to the manufacturers of equipment -a responsibility not found in many Tanzanian industries. It is only in very few cases that the manufacturer offers after sale services due to high costs of such services. Tanzanian industries, as are other third world countries, are geographically far from the manufacturers of the equipment they use. Therefore, it becomes very expensive for them to try to sign an agreement for after sale services. The manufacturer will charge them the costs incurred in providing the service, such as transport of the technical expertise, accommodation, and allowances.

The other task which is peculiar to other Tanzanian maintenance departments, is the analysis of operating information. In many firms in Tanzania, the analysis of the operating information is a responsibility of the production departments. However, operating information can be used in 'Condition Based Maintenance' (ref. chapter 6) to detect a deterioration on the performance of the equipment. Hence, this operating information is a very useful tool in predictive maintenance, and MPG can assume a responsibility of collecting and analyzing this type of information.

Responsibility for safety matters is also different from the Tanzanian situation. In Tanzanian industries, there is a separate safety department headed by a safety engineer (where available) or a safety officer. This position in many situations was created by government regulation which requires each company to create a safety committee for the purpose of combating industrial fire hazards. As a result, a safety officer is responsible for all safety matters in an organization, but, in reality, they are more concerned with fire prevention than workers' safety. The safety situation in many Tanzanian industries is in a pathetic shape. The research which was conducted in the Dar es Salaam area shows that safety regulations are not enforced [18]. In such a situation, putting the safety department under the umbrella of the maintenance department in Tanzania may further jeopardize the already poor safety standards existing.

4.4 MPG Activities (Maintenance Activities):

MPG's daily activities are divided in three main categories: a) Mechanical and Controls activities; b) Technical support activities; and c) Data acquisition. These activities are within the responsibility grouping of MPG. Mechanical and control activities include technical tasks such, as inspections, maintenance failure analysis, condition monitoring, and others. The technical support section is responsible for scheduling the downtime, giving costs and operating information, updating spare parts information, and maintaining a technical library. Data acquisition handles the predictive techniques of performance, vibration , and pulsating testing.

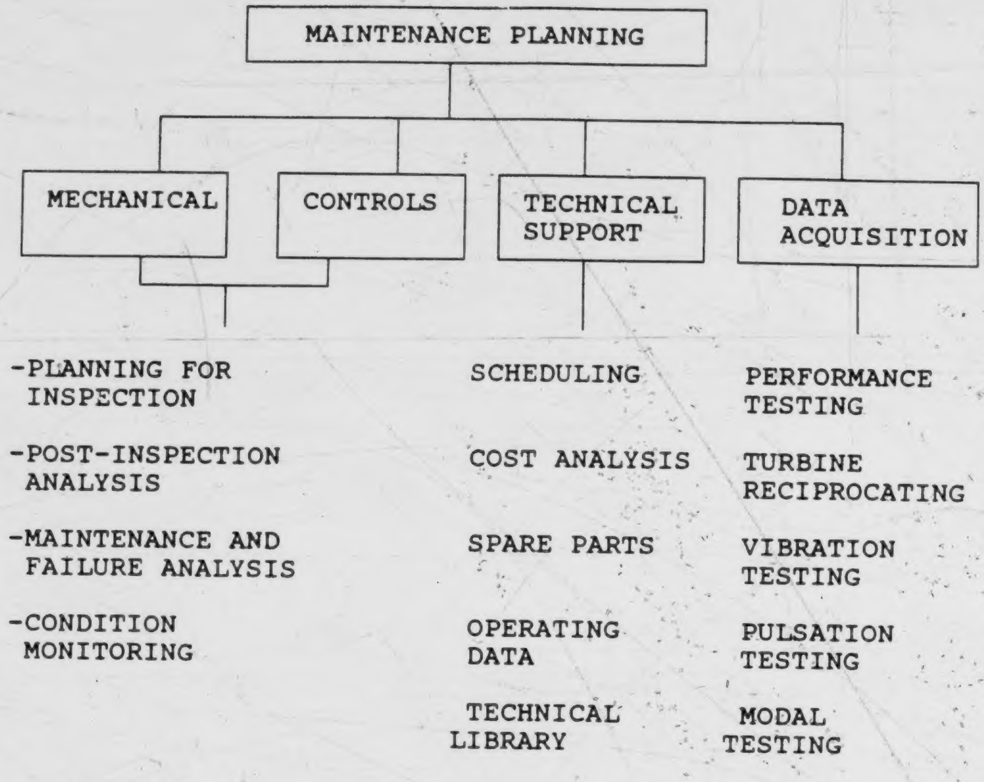

MAINTENANCE PLANNING
MECHANICAL
CONTROLS
TECHNICAL SUPPORT
DATA ACQUISITION
-PLANNING FOR INSPECTION
-POST-INSPECTION ANALYSIS
-MAINTENANCE AND FAILURE ANALYSIS
-CONDITION MONITORING
SCHEDULING
COST ANALYSIS
SPARE PARTS
OPERATING DATA
TECHNICAL LIBRARY
PERFORMANCE TESTING
TURBINE RECIPROCATING
VIBRATION TESTING
PULSATION TESTING
MODAL TESTING

Figure 4-2: Functional Organization of Maintenance Planning

4.4.1 Maintenance Scheduling:

The basic maintenance management functions at AGTD are summarized in figure 4-2 above. From a chronological point of view, the first task is scheduling of maintenance activities which is limited to those that require prior planning. The planned maintenance, which has little or no effect on operation, is roughly scheduled with the actual time of maintenance determined by the maintenance crew. But maintenance actions, that will need an interruption of operation, receive detailed attention because coordination with the departments is required.

Maintenance scheduling can be divided into two steps. The first step is to determine the project inspection date which is based on the inspection frequency and the previous maintenance actions. If the frequency is based on normal elapsed time, only the date of the last inspection is needed to calculate the next inspection date. But if the frequency is based on the running hours, the operating history has to be used to project an average rate of operation in order to calculate the date of the next maintenance action.

The second step is to coordinate the schedule with the maintenance crew which will actually do the work, the operation personnel which will be affected by any planned maintenance, and any other groups which, in one way or another, will be affected. This coordination of different groups is mainly the responsibility of the downtime coordinator. The first step in this process is the estimation of the downtime for the entire calendar year which is made available to all departments to be affected. The second step is to review and adjust the schedule at the beginning of each month. The schedule is discussed and approved at the monthly departmental meeting. Since outside conditions can affect the plans, day to day changes are sometimes made, thus some flexibility must be maintained within the schedule for unforeseen problem.

The important lesson which Tanzanian industries can learn from this scheduling of maintenance activities is the involvement of the maintenance crew which will actually do the work in setting the maintenance time. This, in management theories, is the so called participative management. This process motivates the maintenance crew to perform the maintenance activities in the least possible time: they set the time themselves, and they feel that they are trusted and treated as mature enough to set their own time. This reduces the necessity of having constant supervision of the maintenance crew.

From the questionnaire analysis, it seen that, in many Tanzanian industries, the maintenance personnel are not given full responsibility for the equipment they maintain. But this situation can be rationalized by the fact that most of the maintenance personnel do not possess enough technical skills to be given full responsibility for the equipment. However, even in companies which have qualified engineers, this problem still exists. This demotivates the maintenance crew; they do not feel trusted and responsible. As a result of this, the quality of maintenance performed most of the time is below standard. Whenever people are made to work like robots, the quality of work done is normally adversely affected. If people are given more responsibility, they tend to perform better in their job because they feel more accountable for the work in which they are responsible. Hence, if the industrial managers in Tanzania want an improvement in maintenance departments, they should give more responsibility to the maintenance crews.

4.4.2 Maintenance Planning:

The main aim of maintenance planning is to increase the effectiveness of the maintenance resources which include manpower, tools and equipment, spare parts management, and to minimize equipment outages that affect operation. The following are items that are considered in maintenance planning at AGTD: a) pre-ordering of long lead-time spare parts based on the inspection projection; b) detailed planning before the inspection, including a review of previous equipment history; preparation of inspection tasks; establishment of manpower and downtime required; estimation of costs to be incurred; and determination of spare parts requirements; c) a review of the inspection books with the supervisor of the maintenance crew; d) determination of spare parts availability and preparation of documents for purchase/issuing from inventory; and, lastly, e) preparation of all preventive maintenance work.

4.4.3 Maintenance Analysis and Reporting:

Maintenance analysis is important when the effectiveness of the maintenance department is to be determined. After each inspection or any maintenance activity, the analysis is done so as to evaluate the results and determine the implication of the information for future maintenance of the equipment. This analysis also serves as a yardstick to compare the actual costs, downtime and manpower requirements with the estimates. Another aspect of maintenance analysis is failure analysis. If there is a major failure, or if any failure occurs before the planned maintenance period, an analysis is carried out to determine the cause and to find out ways of avoiding such failure occurrence in future. Details of failure analysis is found in chapter 5 of this thesis. MPG uses almost the same procedures in failure analysis. An effective maintenance analysis provides a justification of necessary improvements in the maintenance system or modification of equipment, provides feedback on the effect of routine maintenance (inspections, scheduled preventive maintenance, etc.) and measures the amount of maintenance in unscheduled maintenance (breakdown maintenance).

4.4.3.1 Computerized Maintenance Management:

AGTD is in the process of normalizing an in-house maintenance software known as MCP (Maintenance Control Program). This software was developed with intentions of:

a) providing centralized data base of maintenance related information for use by all departments within Nova AGTD;

b) eliminating inefficient manual procedures in the maintenance management process; and

c) improving the analysis of maintenance data for use by the technical department and other departments.

MCP can be viewed as a data base of maintenance information. The maintenance personnel can store, manipulate, and retrieve location and equipment information such as:

a) location data (e.g. Station, Edmonton, warehouse, building);

b) equipment fixed data (eg manufacturer, model, size);

c) maintenance history (problems, activities and related costs);

d) equipment inspection procedure (task lists, inspection scheduling, modifications, etc.) and spare parts required; and,

e) operating hours for a location or equipment (Operating hours and time such as months, weeks, etc.); are tracked for every piece of equipment regardless of movement within the company facilities.

MCP initiates timely schedule maintenance appropriate to the equipment, as determined by history and relevant operating cycles. The maintenance schedule report from MCP includes, type of work required to be performed; type and number of personnel; spare parts required; tools necessary to perform the work; and, any special tool needed. Maintenance personnel are able to view any combination of this information on line,

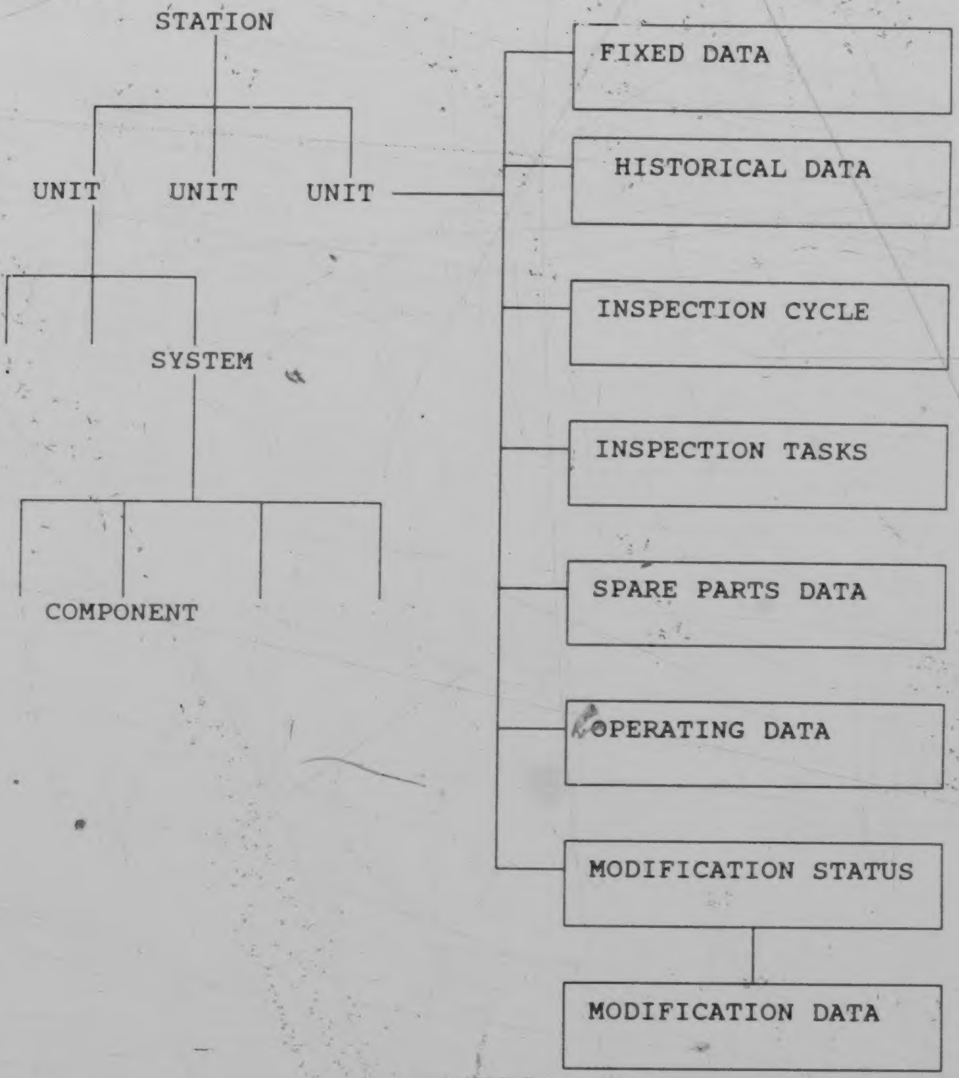

STATION
UNIT
UNIT
UNIT
SYSTEM
COMPONENT
FIXED DATA
HISTORICAL DATA
INSPECTION CYCLE
INSPECTION TASKS
SPARE PARTS DATA
OPERATING DATA
MODIFICATION STATUS
MODIFICATION DATA

Figure 4-3: An Overview of MCP Data Base Information

or print a variety of pre-defined and ad hoc reports. MCP facilitates the production of various maintenance reports for different purposes, such as summary reports for higher level management, detailed information for maintenance crews, ad hoc reports for meetings, reliability and availability reports, and others.

Computer-aided maintenance planning programs can be very complex if all functions are to interact efficiently and effectively. Ease of use of any software ("user friendly"), types of files and their links, and the output information are very important features of any software to all personnel who will need to use it. An overview of MCP data base information is as shown in figure 4-3.

4.4.3.2 Benefits of Computerized Maintenance Management:

The most important benefit of a computerized maintenance management is in report writing where the reports are uniform and understandable to all personnel who are trained to use computers. The reports which MPG has to prepare, either for top management or for maintenance crew include: a) inspection project reports which allow one to determine project inspections for a specified time interval in the future; b) spare parts pre-order report which correlates the inspection information and produces a complete spare parts list so that the long lead time spare parts can be ordered well in advance;

c) a monthly downtime schedule report, which is issued to all departments which will be involved; d) a monthly failure report, a monthly operating report, and the post-inspection report all of which are very important for analysis of failure, maintenance problems and effectiveness of the maintenance programs; and f) cost reports which provide the actual maintenance costs used in comparison of the estimated costs with the real costs.

The use of the PWE form (Problem report, Work request, Equipment maintenance report) helps in generating uniform reports which are concise and understandable to all personnel. The first part of the report explains the problem, and is mainly completed by the operational personnel. The second part of the PWE form is a work request which explains the type of work required to arrest the problem. The third part of the PWE form, which is specific to one piece of equipment, shows the maintenance work done on the equipment. This shows the action taken, parts used and future action required. All this information from the PWE are fed into the MCP's data base.

The importance of record keeping is overlooked in many Tanzanian industries. The questionnaire analysis showed that about 50 % of those who responded did not keep records of the maintenance activities done on the equipment. From MPG's point of view, it is almost impossible to design and install an effective maintenance plan without the past records of the performance of or work done on equipment. However, record keeping is a cumbersome task if detailed information regarding the equipment is to be kept. For small firms, manual record keeping can be sufficient at the initial stage when there are few data to keep. After some years of record keeping, it is obvious that the amount of information available is too big to continue with manual record keeping, otherwise it will be very tedious to retrieve and manipulate any information from a data base. However, with the advent of new, powerful, cheaper computers, which can be afforded by even a very small firm, a computerized maintenance information processing is highly recommended.

Standardization of data, improvement of data quality, consistency, maintenance and failure analytical capabilities, less effort to modify any information, are among the very many benefits of computerized maintenance activities. A company can take into consideration the possibility of building its own maintenance software package, however, the cost of maintenance software packages in the market is not prohibitive. Appendix 3 shows some of the maintenance software packages available in the market. These packages can be tailored to suit the specific needs of any firm.

5.0 Failure Analysis, Maintainability, and Reliability:

5.1 Failure Theories:

An effective maintenance management system is based on failure analysis. Failure analysis is not a new subject; many authors have written about failure, failure analysis and application of failure data in maintenance of equipment. The following texts are among the most recent literature on failure analysis: J. Davidson, **The Reliability of Mechanical Systems** [20], B.S. Dhillon and H. Reiche, **Reliability and Maintainability Management** [21], J.H. Bompass-Smith, **Mechanical Survival: The use of Reliability Data** [22]. In this thesis, failure theories will be reviewed with the aim of utilizing failure data in designing an optimum maintenance management system.

Failure of a component or part of a piece of equipment occurs at a point where stress toward which a part is subjected exceeds the strength of the part at that time. During the design stage, a component is designed with some distribution of strength into it. When the equipment is on duty (i.e. is loaded), there is another distribution of stress imposed upon the component. For a totally no failure situation, the probability density functions (pdfs) of these two distributions are completely separated. This situation is shown in figure 5.1. In this situation, the component will, ideally, never fail because the load is always lower than the strength of the component.

If the probability density functions of the strength and the load interfere as is the case in figure 5.2, then the shaded area where the curves intersect represents the area where failure will occur. In this situation and others where the load exceeds the strength of the component, failure is expected to take place. In other words, it can be inferred that failure occurs when the strength of a component and the load imposed on it become incompatible.

Failure analysis is a useful tool in determining the effectiveness of maintenance programs and in predicting subsequent maintenance actions. Although failure analysis is normally done at a component level it can also be applied to systems and major capital equipment. Failure analysis can be applied in designing optimal maintenance strategies and in obtaining information about availability and reliability of equipment. There are a lot of analytical methods available for failure analysis. With an increase in computer applications in data analysis, which allows evaluation and analysis of large amounts of data, it is possible to utilize the maintenance failure data analysis in maintenance planning.

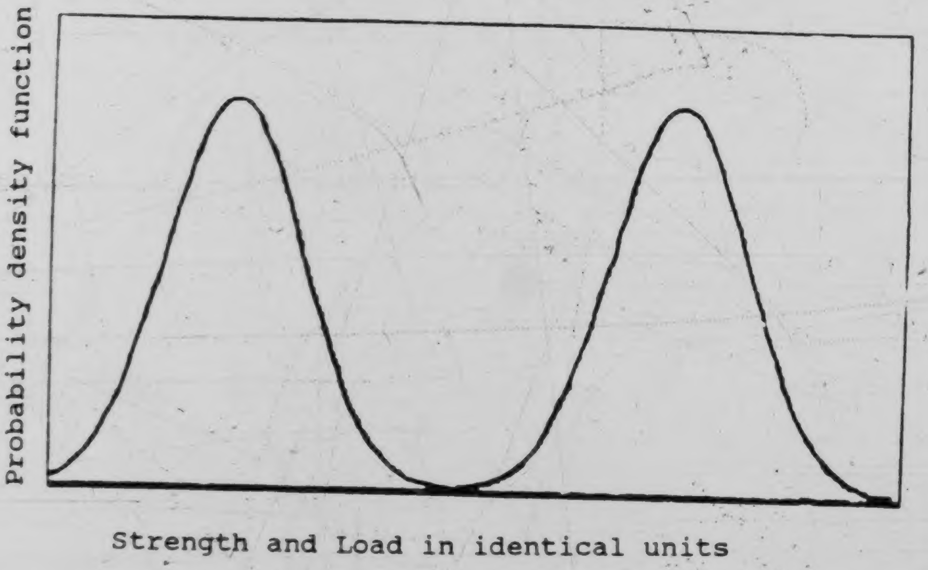


Figure 5-1: Strength-Load Diagram with Complete Separation

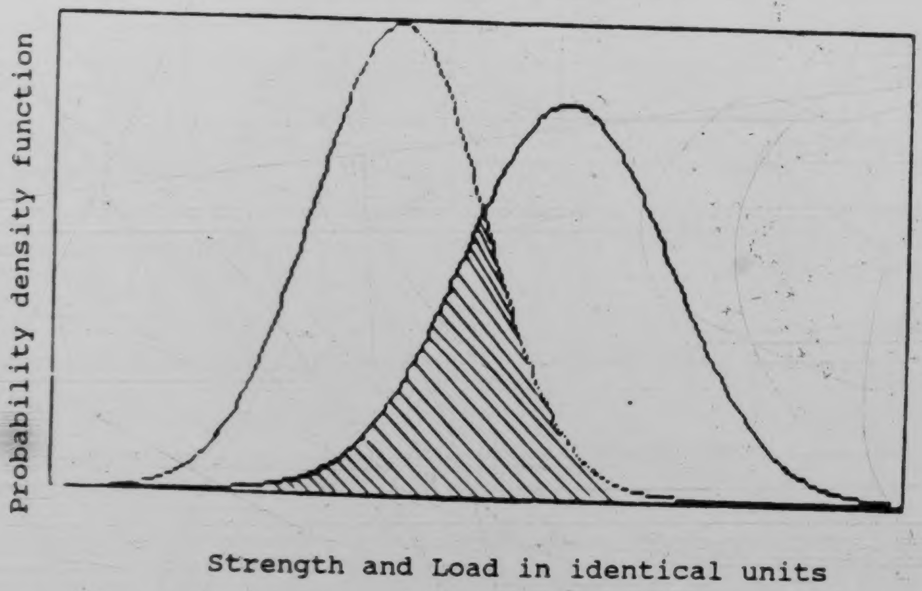


Figure 5-2: Strength-Load Diagram with Interference

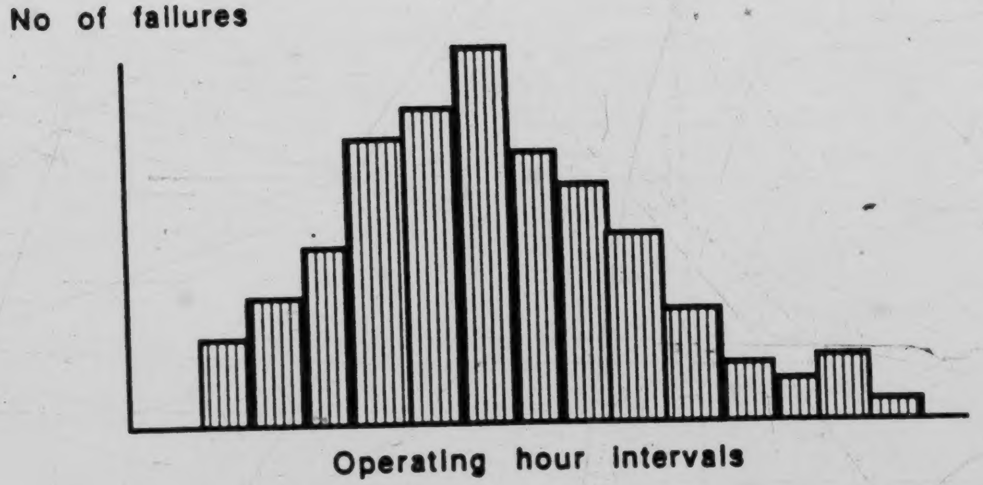


Figure 5-3: Failure Histogram

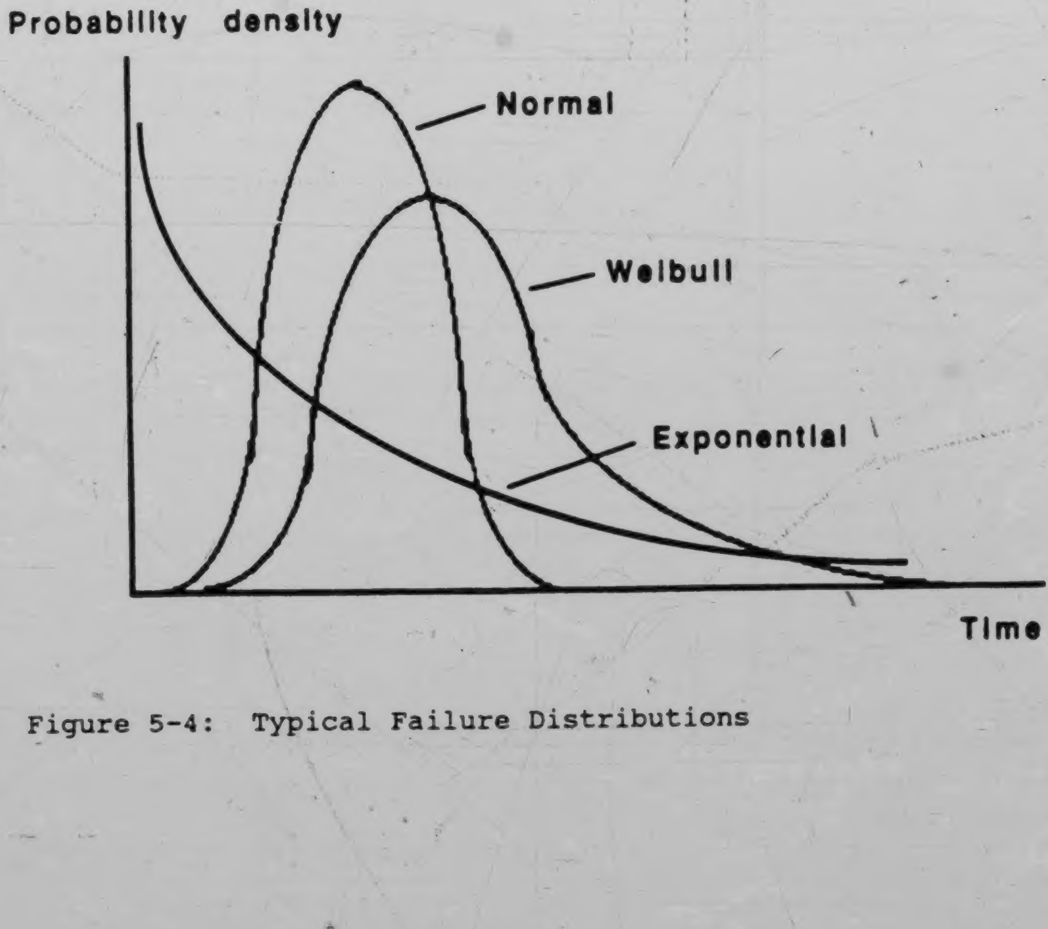


Figure 5-4: Typical Failure Distributions

The first step in failure analysis is to determine the intervals between failures. The intervals can be operating hours, number of cycles, days, etc., or any time measurement parameter. The second step is to present the failure data so as to give it a meaningful interpretation. Pareto failure analysis is one of the simplest techniques in presenting the failure data. However, the failure data can be presented in any other form. The commonly used method apart from Pareto analysis is graphical presentation of the data.

The graphical presentation of failure data can either be by histograms, as in figure 5.3, or by smooth curves of probability functions, as in figure 5.4. Smooth curve presentation is mostly preferred, especially when it is necessary to interpret whether the failure rate is increasing, decreasing or remaining constant. The following are among the distribution functions used in presenting the failure data: Normal distribution, Weibull distribution, Log-normal distribution, and Binomial distribution. Normal and, especially Weibull distributions are highly preferred in failure data analysis, the latter of which has the advantage of being able to handle skewed distributions.

Normal distribution is used to analyze increasing failure rates, while exponential distribution is used to analyze constant failure rates. Weibull distribution can be used to analyze increasing, decreasing and constant failure rates; indeed, the Weibull distribution can be used to estimate both the exponential and Normal distributions. The Normal distribution is reviewed in appendix 4.

However, failure data may neither be normal distributed nor Weibull distributed. These two analyses are only used to estimate the type of distribution so as to be able to predict the next failure. Graphical failure analysis is just a statistical analysis in which some errors are almost impossible to avoid, whereas in deterministic physical relationships (such as Hook's law) errors can almost always be avoided.

5.1.1 Pareto Analysis:

Pareto analysis puts more emphasis on the total failure cost than just on the frequency of occurrence. In Pareto analysis, the frequency of each defect is recorded together with an estimate of the cost [23]. The frequency is then multiplied by the cost and the result is the total cost penalty for each type of failure. The defects are then arranged in a descending order of their total cost; the defect with the highest cost is placed at the top, and that with the lowest total cost is placed at the bottom. An example of Pareto analysis is shown in table 5-1.

Pareto analysis imply that total cost of failure can be drastically reduced by concentrating effort on one type of defect. As apparent from table 5-1, 43% of the failure cost could be saved by concentrating effort on valve defects only. Pareto principle can be dictated as "attack the main source of the unreliability in order to produce the maximum gain" [24].

Table 5-1 Pareto Analysis

TYPE OF DEFECT	FREQUENCY	COST	TOTAL COST	% OF TOTAL
Valves	15	$300	$4500	43
Control panel	10	200	2000	19
Fuse board	25	75	1875	18
Hydraulic system	3	450	1350	13
Others	47	15	705	7
Total			$10430	100%

5.1.2 Weibull Distribution Function:

Weibull distribution function originated from fatigue test studies [25]. The fact that the distribution was derived empirically implies that it has a significant feature in practical application. Weibull distribution function has the following features which are very attractive in failure analysis: a) the distribution function is very flexible (it can deal with increasing, constant and decreasing failure rates); b) its mathematical simplicity makes it easy to use; and c) the function can be easily used for graphic analysis. Weibull distribution function is defined by equation 5.1 [26] and, by differentiation of equation 5.1, it is possible to get the Weibull probability density function f(t) as shown in equation 5.2:

$$F(t) = 1-\exp[-(\frac{t-\gamma}{\eta})^{\beta}] \qquad 5.1$$

$$f(t) = \frac{dF(t)}{dt} = \frac{\beta(t-\gamma)^{\beta-1}}{\eta^{\beta}}\exp[-(\frac{t-\gamma}{\eta})^{\beta}] \qquad 5.2$$

where

$t = time\ parameter \quad \beta = shape\ parameter$

$\gamma = time\ at\ F(t) = 0,\ it\ is\ datum\ parameter$

$\eta = scale\ parameter$

5.1.3 Plotting the Weibull Distribution:

Starting with equation 5.1, it is possible to get equation 5.3, and by taking the natural logarithm twice on equation

5.3, result in equation 5.4. If equation 5.4 is plotted on log-log paper, a linear graph is expected. Weibull probability graph paper is found on the market and can be used to plot equation 5.4. Typical Weibull distribution functions are shown in figure 5.5 and Weibull plot on a graph paper is shown in figure 5.6 (a graph paper as produced by Chartwell [27]). For a particular case, 'ß', 'γ' and 'η' are constants. 'ß', which is the slope of the line, represents the rate of change of failure rate over time.

There are at least four characteristics of F(t) at various 'ß' values: a) $\beta<1$: F(t) decreases as t increases. This is the case of decreasing failure rate with time. This case is indicated in the first part of the 'Bath-tub curve' (see figure 5-7). b) $\beta=1$: In this case $F(t)=1-\mathrm{Exp}[-(t-\gamma)/\eta)$ which is a negative exponential distribution function. This shows a constant local failure rate which is the second phase of the 'bath-tub curve'. c) $1<\beta<2$, gives skewed distribution functions which show a rapid decrease of $F'(t)$ as t approaches 0. This represents an increase in the failure rate with time. d) $\beta>2$: the distribution becomes more symmetrical as the values of ß increases. At $\beta=3.2$ the Weibull distribution function is approximately equal to the Normal distribution function. This also is the case for increasing local failure rate.

$$1-F(t) = \exp[-(\frac{t-\gamma}{\eta})^{\beta}]$$

$$\frac{1}{1-F(t)} = \exp[(\frac{t-\gamma}{\eta})^{\beta}] \qquad 5.3$$

$$\ln\ln[\frac{1}{1-F(t)}] = \beta\ln(t-\gamma)-\beta\ln(\eta) \qquad 5.4$$

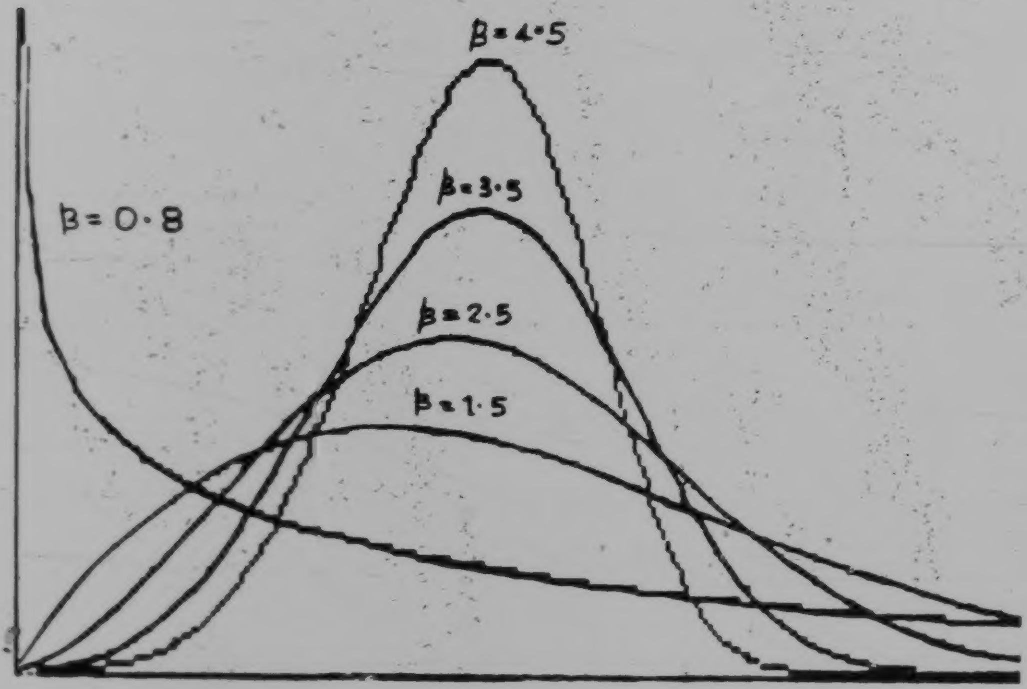
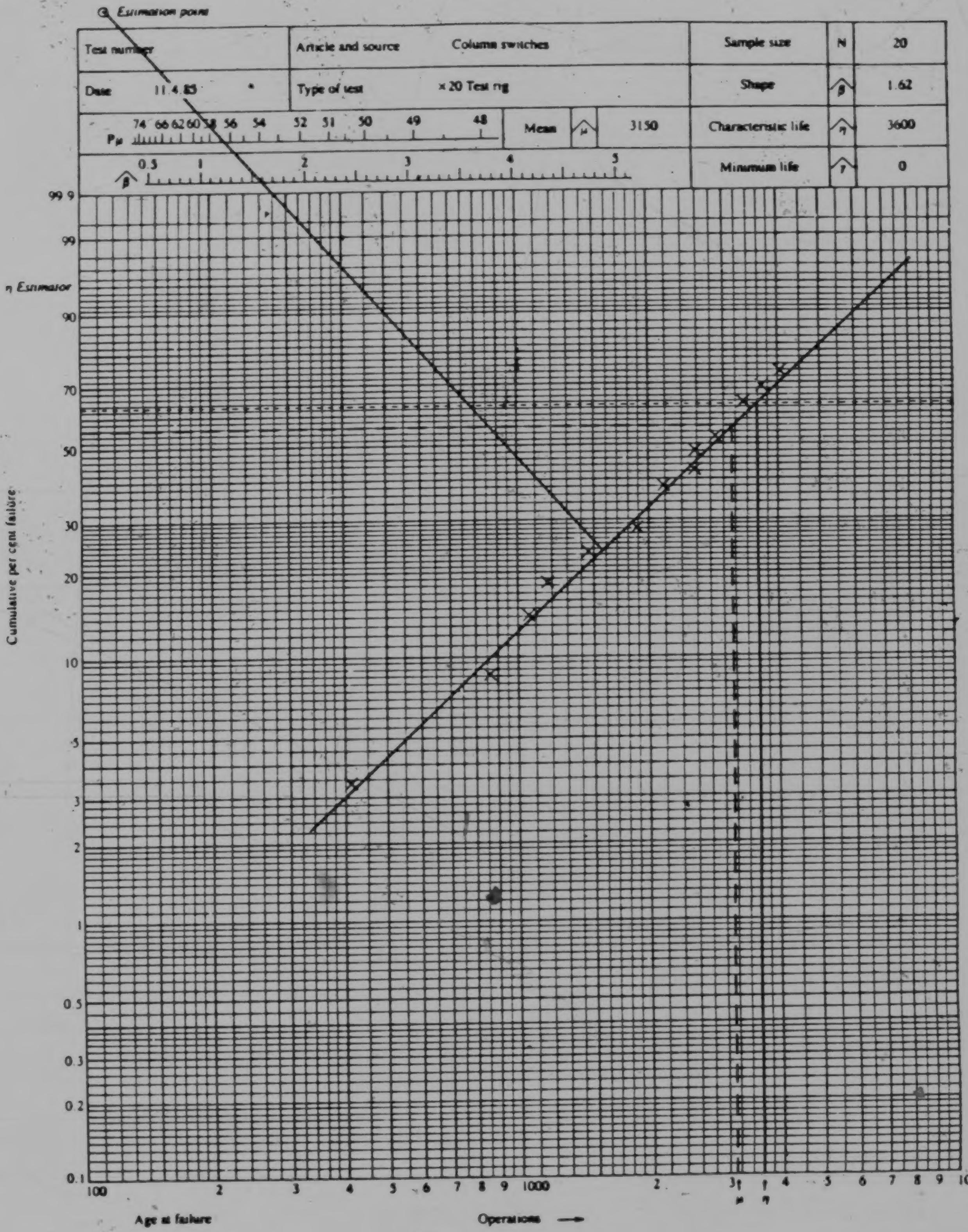


Figure 5-5: Typical Weibull Distribution Functions



Test number	Article and source Column switches	Sample size	N	20
Date 11.4.85	Type of test ×20 Test rig	Shape	$\hat{\beta}$	1.62
P_μ	Mean $\hat{\mu}$ 3150	Characteristic life	$\hat{\eta}$	3600
$\hat{\beta}$		Minimum life	$\hat{\gamma}$	0

Figure 5-6: Typical Weibull Plot on Log-Log Graph

5.2 Reliability:

Reliability, in common language, refers to ability to perform a required task satisfactorily without failure. Mechanical reliability is the probability that a component, device or system will perform its prescribed duty without failure for a given time when operated correctly in a specified environment.

Reliability = The probability that an item will perform satisfactorily for a specified period of time under a specified operating condition [28].

The key parameters in defining reliability are: probability; satisfactory performance of duty; specific time interval; and operating conditions. Probability occurrence refers to occurring by 'chance' or 'betting odds'. By contrast, other events which are controlled by natural physical laws, and which can be predicted with certainty, are known as deterministic occurrences.

Performance of prescribed duty refers to the proper use of a device, and must be specified so as to exclude failures caused by abuse of equipment. Time interval is among the parameters which affect the reliability of an equipment. There is no mechanical device which can operate for an infinite period of time; every device is susceptible to failure. The number of cycles in which an item performs may be the governing factor which affects its failure and, thus, its reliability.

Operating condition refers to the environment in which the equipment will be operating. Some environmental conditions such as high humidity, dust, and high temperature may accelerate the wear of a component and, hence, its failure. Some electronic devices must be isolated from normal atmospheric conditions, while in operation otherwise they will fail. Hence, in defining failure of equipment, it is important to define the environment which the equipment was designed for, and the environment in which the equipment is being operated.

Reliability at time t, denoted as R(t); from a statistical point of view R(t) = 1 means absolute reliability and no failure will occur. But, as explained earlier, there is no mechanical device which is not susceptible to failure, hence, R(t)<1 for all mechanical devices. Another function known as F(t) denotes the unreliability of a component at time t. F(t)=1 means absolute unreliability and failure must occur. The definition of unreliability is:

Unreliability =The probability that an item will not perform satisfactorily for a specified period of time under specified operating conditions [29].

$$R(t) + F(t) = 1 \tag{5.5}$$

F(t) is the probability that failure will occur, whereas R(t) is the probability that failure will not occur. The probability density distribution function of failure is denoted as f(t), and the probability function F(t) is defined by equation 5.6 as:

$$F(t) = \int_0^t f(t)\,dt \qquad 5.6$$

Hence, if the mortality curve (failure curve) is known, it is possible to find the probability density distribution function by differentiation:

$$f(t) = \frac{dF(t)}{dt} \qquad 5.7$$

5.2.1 Failure Rate:

Failure rate is defined as the number of failures per period of time during which failure can occur. Failure rate is normally presented in terms of failures per hour or other multiples of hour. Failure rate can also be presented in terms of the number of operations or number of cycles. Another important parameter in defining failure rate is the failure rate per unit time z(t), where t is the lifetime of the equipment under consideration:

$$z(t) = \frac{\text{Number of failures expected during a unit of time at a given lifetime}}{\text{Number of items exposed to failure at the same lifetime}}$$

Other terms used to define the failure rate per unit time z(t) are: force of mortality, age specific failure rate, instantaneous failure rate, conditional failure rate, hazard rate function, local failure rate, etc.. In this thesis, the term local failure rate will be used. Local failure rate may be defined as the probability that a component will fail in the next time interval given that it has survived up to the beginning of that time interval. Probability of failure in the next time interval is given by [30]:

$$\begin{aligned} z(t)dt &= \frac{F(t+dt) - F(t)}{R(t)} \\ &= (dF(t)/dt)/R(t) \\ &= \frac{f(t)}{R(t)} = \frac{\text{Probability density function}}{\text{Reliability}} \qquad 5.8 \end{aligned}$$

Local failure rate z(t) is utilized in building the famous 'Bath-tub curve'. The 'Bath-tub curve' has three phases; phase one is known as the declining local failure rate phase. This situation happens to new machinery due to latent defects in materials and poor workmanship. Since the failure of components in this phase is premature, this phase is sometimes known as the 'infant mortality phase', the 'Burn-in phase', or as 'early failures'. The 'bath-tub' curve is shown in figure 5-7.

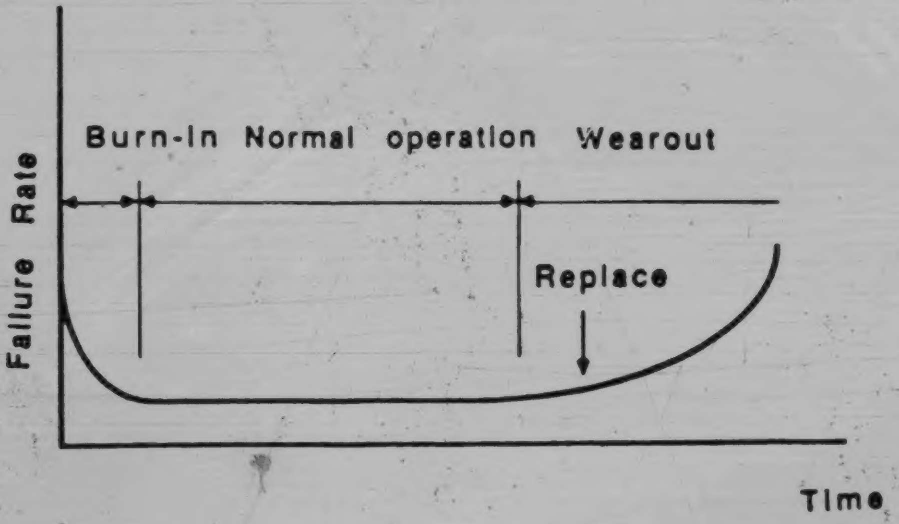


Figure 5-7: Bath-tub Curve

Phase 2 is known as the component's 'normal operating life', 'constant failure rate', 'random failure', 'stress-related failure', or as 'stochastic failures'. The local failure rate in this phase is constant and occurs by random fluctuations of stress exceeding the component strength. Failures in this phase occur by chance due to unexpected over-stressing of components.

In phase three, the failure rate of a component increases over time. This phase is known as the 'wear out phase' which is comparable to 'ageing' in people and indicates the ending of the life of a component. This may be caused by corrosion, oxidation, breakdown of insulation, atomic migration, friction wear, shrinkage, fatigue, etc.. Hence, by being able to build a 'bath-tub' curve of a component, it is possible to estimate its life span.

5.2.2 Availability:

Availability can be defined as the proportion of time during which a piece of equipment is in operational or able to run if required. Total time, in this case, is the time during which the equipment was expected to be running.

$$\text{AVAILABILITY} = \frac{\text{Total time} - (\text{Scheduled \& unscheduled downtime})}{\text{Total time}}$$

$$= \frac{\text{MTTF}}{\text{MTTF} + \text{MTTR} + \text{MWT}} \qquad 5.9$$

Where MTTF = Mean Time To Failure

MTTR = Mean Time To Repair

MWT = Mean Waiting Time

Downtime in this situation is the time during which the equipment was required to be running but was down due to malfunction and/or scheduled downtime for preventive maintenance. This should be clearly distinguished from the time in which the equipment was not expected to be running, such as during a single shift operation in which the equipment is not expected to be running for at least 16 hours. For example, if the equipment which was running for 8 hours in a single shift operation, was down for the past three days, the total downtime is only 24 hours and not 72 hours.

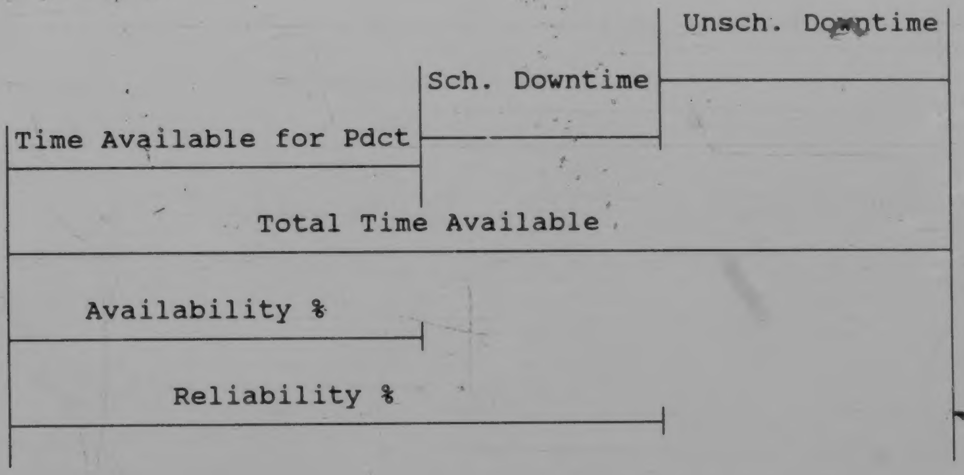

Unsch. Downtime
Sch. Downtime
Time Available for Pdct
Total Time Available
Availability %
Reliability %

Figure 5-8: Availability and Reliability

Availability depends on both the failures (unplanned maintenance) and the amount of planned maintenance whereas reliability reflects only the time lost due to failure.

$$\text{RELIABILITY} = \frac{\text{Total time - Unscheduled downtime}}{\text{Total Time}} \qquad 5.10$$

The relationship between availability and reliability is shown diagrammatically in figure 5-8.

5.2.2.1 Factors Affecting Availability:

The two major factors which affect availability are the amount of planned downtime and unexpected downtime, which means that availability depends on the amount of planned maintenance and unplanned failures. In addition to that, there are four other factors which contribute to achieving high availability. These factors are: environment; the maintainability of the equipment; the inherent reliability of the equipment; and the human reliability factor. These factors interact with each other to produce the final availability of the equipment.

Unscheduled maintenance is one of the major contributors to low equipment availability. Whenever a failure occurs, there are at least five steps to restore the situation: notification of the failure; diagnosis of the problem; resource allocation to carry out the work; the repair work itself; and testing of the equipment to ensure operational reliability. Effectiveness and efficiency of doing each step are important in minimizing the amount of downtime. The number of failures may be very low, but the downtime may be excessive due to unavailability of resources such as spare parts and/or personnel.

In contrast to unplanned maintenance, scheduled maintenance is planned in advance and the downtime is only affected by the methods of doing the maintenance work. The downtime is affected by the skill of the maintenance personnel, the amount of maintenance work itself, availability of spare parts and technical support. But things may not always go as expected and the ability to respond to changes during the maintenance work is very important in reducing the downtime and increasing the availability of the equipment. In planned maintenance the scheduled downtime includes: time to disassemble; time to investigate condition; time to replace the planned parts; time to do the planned repairs; time to acquire and place the unplanned parts; time to do unplanned activities; time to reassemble; and time to test.

The environment in which equipment is operating has a direct impact on its availability. The environment influences both the number of failures and their severity. Consequently this affects the frequency and the scope of the planned maintenance. Temperature at either end of the spectrum can cause problems in an operating piece of equipment, especially if the design limits are being approached. The effectiveness of the cooling system has to be maintained if high ambient temperatures exist, and consumables, such as lubricants may have to be checked more frequently.

Inherent reliability of equipment refers to the latent defects in components of the equipment. If a weak point exists in the design of a piece of equipment, especially the critical components, and is possibly accentuated by environmental conditions, the result may be a disastrous failure of the equipment, even for very new equipment.

Human error is a difficult subject to address because it is difficult for individuals to accept their mistakes and become responsible for whatever the outcome will be. Sometimes failures are caused by human error and maintenance activity may be prolonged due to a miscalculation by the maintenance personnel. If the skill of the maintenance personnel is low, the chance of making mistakes is increased. This situation may be exacerbated by lack of proper training, complexity of the equipment and additional external stress such as heat, noise and long working hours.

5.3 Maintainability:

Maintainability can be defined as the inherent characteristic of a design or installation that determines the ease, economy, safety, and accuracy with which maintenance actions can be performed [31]. Maintainability represents the amount of effort required to restore a piece of equipment or the effort needed to perform preventive maintenance within the required limits. In terms of probability, maintainability is the probability that a failed item will be restored to operational effectiveness within a given period of time when the repair action is performed in accordance with the prescribed procedures.

5.4 Application of Failure Data, Reliability and Maintainability:

5.4.1 Economic Aspect:

Information about the reliability of equipment can be used to estimate its economic life. Also, the information can be utilized in designing maintenance system for optimal maintenance strategy. By using the 'bath-tub curve', it is possible to learn whether a device has started to wear-out or if it is still in the 'normal operation' phase. This analysis is helpful in estimating the remaining life of the device.

5.4.1.1 Estimation of Equipment Economic Life:

By multiplying the values of the local failure rate, z(t), by the cost of failure, it is possible to obtain the curve of failure cost per hour [32]. When the curve of failure cost per hour is superimposed on the curve of replacement cost, the resulting curve shows the economic life of the device. At the intersection of the cost of failure curve and the cost of replacement curve is the economical replacement time of the device. This situation is presented in figure 5-9

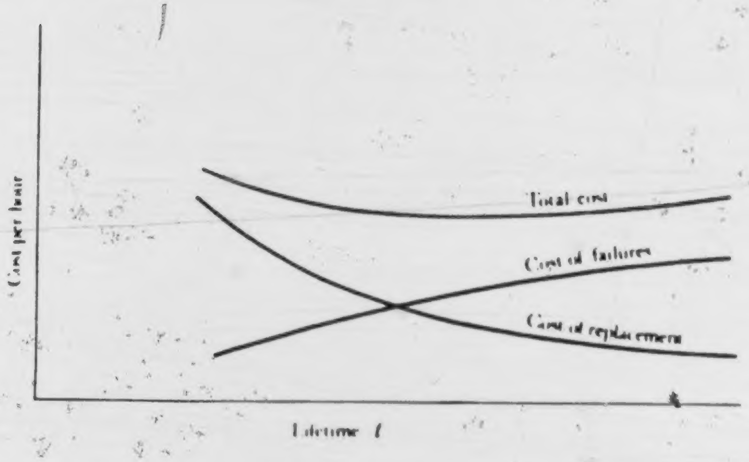


Figure 5-9: Failure/Replacement Costs Curve

5.4.1.2 Optimal Maintenance Strategy:

Failure data and reliability information analysis can assist in designing a maintenance system based on the cost of maintenance. From that information it is possible to decide whether to carry out maintenance by repair or by replacement.

Starting with the smallest component in a unit and by analyzing the failure rate using the Weibull curve, it can be determined whether the failure rate is increasing, decreasing or is constant. If the failure rate is decreasing or is constant, breakdown maintenance is the best alternative since the replacement would not improve the failure rate.

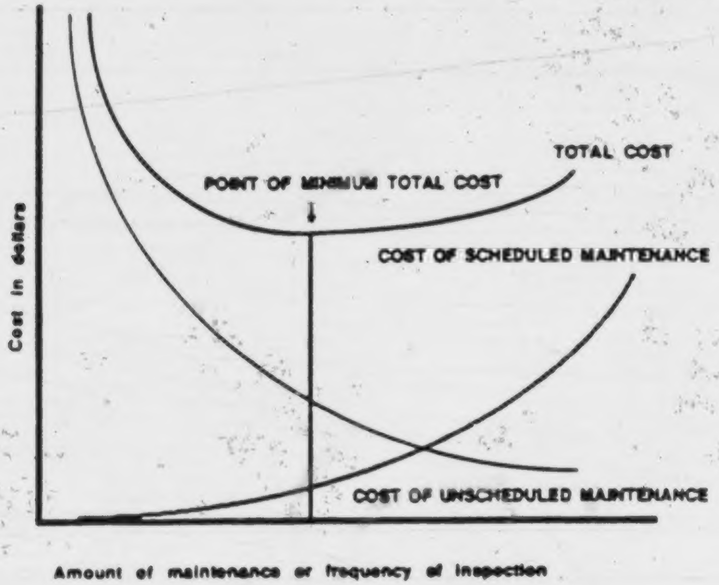


Figure 5-10: Maintenance Optimization

However, when the 'wearout' occurs (i.e. the failure rate is increasing), the best alternative would be maintenance by replacement. In the later case, maintenance actions can be scheduled since failure rate can be defined, and the failure trend can be known. In contrast, when the failure rate is constant, no failure trend can be known since the failure is stochastic, and it happens at a random time interval. With good failure data, it is possible to determine the optimal interval for repair or replacement. Various criteria for optimization of maintenance activities exist, and are based on: total cost; equipment reliability; equipment availability;

and safety. Figure 5-10 illustrates maintenance optimization based on total cost.

5.4.2 Engineering Aspect:

Engineering aspects of maintenance involve application of data from maintainability. Increasing complexity in design of equipment and its accessories means an increase in complexity in maintenance and repair tasks. A good design of equipment should take into consideration its maintainability, its installation, the special tools required, and the quality of the maintenance manuals. The designer must be aware of the maintenance environment and of the possible equipment failure modes. The following design parameters, from a maintainability point of view, would improve maintenance and increase equipment availability:

i) Access - Low-reliability parts should be easily accessible and must be easily removable with minimum disturbance. For 'Least Replaceable Assembly (LRA)', it should be possible to remove each LRA without removing any other LRA.

ii) Connections - Wherever possible, the use of detachable joints should be encouraged. Since detachable joints are more likely to fail than fixed joints, a trade-off between reliability and maintainability should be considered during design stage.

iii) Ergonomic factors - This involves the weight, size and shape of removable modules. Heavy removable modules will complicate the maintenance work; over-miniaturized equipment is prone to incidental damage. Safety and comfort of maintenance personnel should be taken into consideration.

iv) Interchangeability - Easily interchangeable equipment simplifies diagnosis, replacement and checkout. By using standard elements whenever possible, the hassle of storage of different kinds of spare parts will be reduced.

v) Test points - The check points are for diagnosis, adjustment, checkout, calibration and monitoring of equipment. Test points are the interface between the testing device and the equipment under test, and should be easily accessible, if possible, without dismantling any part of the equipment under test. Standardization of check point positions will reduce the probability of incorrect diagnosis which results in incorrect actions.

6.0 Industrial Maintenance Systems (IMS):

Industrial maintenance systems (IMS) refers to different maintenance management techniques which can be applied in industries so as to attain the maintenance objectives. The following are the main known maintenance objectives:

i. to extend the useful life of equipment;
ii. to ensure the optimum availability of installed equipment for production;
iii. to increase reliability of equipment, i.e., to ensure instant readiness of all equipment for emergence use; and,
iv. to ensure the safety of equipment and personnel.

A lot of literature has been written about maintenance management systems, a few of which were used in writing this thesis: J.D. Patton Jr., **Preventive Maintenance;** B.W. Niebel, **Engineering Maintenance Management**; T. Wireman, **Preventive Maintenance**; A. Kelly, **Maintenance Planning and Control**; and, Brig.S.S. Apte, **Plant Maintenance**. To summarize the benefit of a good Industrial Maintenance System (IMS), it can be concluded that a good IMS will:

i. reduce the overall production costs;
ii. increase productivity;
iii. increase the efficiency of the equipment;
iv. be based on economical as well as the managerial and organizational aspect of maintenance;

v. result in better conservation of equipment and increased life expectancy: this will result in less cash outlays for replacement of plant and equipment;

vi. result in better quality goods and/or services, since the equipment will be always in good running condition, thus producing fewer defective products and less scrap; and,

vii. increase the safety for the workers and improve protection for the plant: this will result in less insurance costs and less compensation costs.

6.1 Types of Maintenance:

Terminology: There are mainly four types of maintenances, but many different terms are used by different authors to describe them. These types are outlined on figure 6-1. For the sake of consistency, the following terms will be used in this thesis with the other similar terms in parentheses:

6.1.1 Breakdown Maintenance: **(Repair Maintenance, Corrective Maintenance, Unscheduled Maintenance, Emergency Maintenance)**

This is a type of maintenance which is done after failure has taken place. Failure, in this situation, can be either an abrupt type of failure or a gradual failure which was not noticed.

6.1.2 Preventive Maintenance: **(Scheduled Maintenance, Regular Preventive Maintenance, Planned Maintenance)** Doing regular maintenance at a pre-planned time interval. These regular maintenance activities can be accompanied by inspection which will clarify the condition of the equipment, but this type of maintenance is mainly based on time interval. This can be done while the equipment is either running or shutdown.

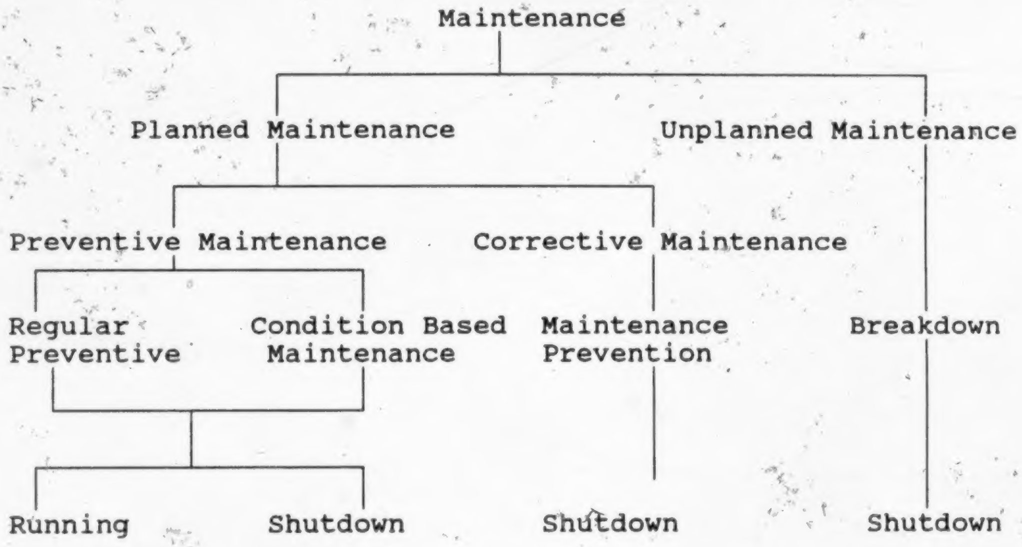

Maintenance
Planned Maintenance
Unplanned Maintenance
Preventive Maintenance
Corrective Maintenance
Regular Preventive
Condition Based Maintenance
Maintenance Prevention
Breakdown
Running
Shutdown
Shutdown
Shutdown

Figure 6-1: Types of Maintenance

6.1.3 Condition Based Maintenance: **(Predictive Maintenance)** This is a special type of preventive maintenance in which a continuous monitoring of the condition of the equipment is done and maintenance is done only when necessary. This also can be performed in either a running or shutdown condition.

6.1.4 Maintenance Prevention: **(Corrective Maintenance, Design-out Maintenance, Renovative Maintenance, Improvement Maintenance)** Design or redesign of the equipment or part of the equipment for minimal or, ideally, no maintenance. The re-design of the equipment or part of the equipment can take place either while the equipment is running or is shutdown.

6.2 Breakdown Maintenance (BM):

Breakdown Maintenance is a type of maintenance done after failure has occurred. Normally, this failure happens without any pre-noticed signal of failure, and can be either an abrupt failure, or a gradual failure which had not been monitored. In some literature there is another type of breakdown maintenance known as 'planned breakdown maintenance'. In this thesis, breakdown maintenance will refer to an emergency type of maintenance without any pre-known failure trend and, hence, no pre-planned activities before the failure has taken place will be assumed. The planned breakdown maintenance will fall under 'Condition Based Maintenance'. Normally, breakdown maintenance is done on trivial equipment whose failure has no important consequences on production and/or the safety of the operator.

6.2.1 Advantages and Disadvantages of Breakdown Maintenance:

Breakdown maintenance has initial low costs, and it minimizes the maintenance work, provided that no serious problem of secondary damage occurs. In breakdown maintenance there is no planning hassle. If the maintenance personnel can overcome the series of breakdowns in minimal time, if there are no injuries as a result of the breakdown, and if the cost of lost production is not excessive, then the people who practise breakdown maintenance can justify the effectiveness of their breakdown maintenance system. Breakdown maintenance can be cost effective if failure can be tolerated, which implies that the breakdown does not affect the operation, safety or integrity of the system.

The main disadvantage of breakdown maintenance is its effect on the plant reliability which is drastically reduced whenever a breakdown takes place. Also, since breakdown can occur at any time, it is more difficult to plan the ensuing maintenance work given that the necessary tools and other resources required to restore the broken equipment may not be readily available once the failure has occurred. In that case, breakdown maintenance takes longer to rectify than a planned maintenance and thus become more expensive. Breakdown maintenance, to be effective, needs to have spare equipment, known as standby equipment, to be installed when the other equipment fails. This is a very expensive alternative since it ties up capital, a scarce commodity in Tanzania. However, on trivial things such as corridor lamp bulbs, tyres, etc., which can be easily replaced, breakdown maintenance is the most economical form of maintenance.

Whenever failure occurs, more emergency downtime is required in breakdown maintenance which include notification time, travel time, diagnosis of the problem time, repair time, and testing time. Breakdown maintenance also needs high spare parts inventory because it is not certain when failure will occur and what type of spare parts will be needed.

6.2.2 Implementation of Breakdown Maintenance:

6.2.2.1 Selection of Equipment for Breakdown Maintenance:

The following criteria may be followed in selecting equipment or part of an equipment for breakdown maintenance:

i. Accessibility - The component should be easily accessible; preferably, it should be an external part of the equipment.

ii. Time to fix - The component should take as minimal time as possible to fix and test the equipment when there is a failure.

iii. Safety - The failure of the component should not endanger the life of the personnel or the equipment.

iv. Secondary failure - The failure of the component should not cause failure to another part(s) of the equipment.

v. Critical element - The component for breakdown maintenance should not be a critical element. The failure of this element should not cause excessive loss in production.

vi. Breakdown maintenance can be carried in equipment that has a back-up or stand-by system. The secondary system can be operated while the primary is being repaired.

vii. If the cost of dismantling the equipment for repair is lower than or equal to the cost of removing the item found on inspection (preventive maintenance), then breakdown maintenance may as well be conducted on such piece of equipment.

viii. For equipment that has a long enough life to meet 'minimum equipment life' without preventive maintenance, breakdown maintenance may be used without affecting the production.

6.3.0 Preventive Maintenance (PM):

Preventive maintenance is a pre-planned maintenance which is normally done at a fixed time interval. Preventive maintenance is normally accompanied by a regular inspection of the condition of the equipment, but those inspections are also done at a pre-planned time interval. This is the main difference between the regular inspection and condition monitoring which is done in (ideally) continuous time. Activities in a preventive maintenance are scheduled well ahead of time.

Preventive maintenance is normally done on equipment whose reliability is of high importance. A failure of equipment, such as safety valve, can be very disastrous not only to production, but also to the operator. In other equipment, the failure can be harmless to the operator, but will cause a very big loss to the company and such a repair takes a very long time. In these two cases and others whereby high plant reliability is of utmost importance, regular preventive maintenance is normally recommended.

6.3.1 Disadvantages of Preventive Maintenance:

i. Operating period between planned maintenance cannot be determined precisely because of differences between plants, operating condition and operators' skill.

ii. Over-maintenance problems sometimes occur. In some cases, a part of a piece of equipment can be discarded while it is still intact. This is a set back, especially in a country like Tanzania, because spare parts are very expensive and most of them are imported.

iii. If frequency of regular preventive maintenance is too high, the maintenance costs soar and become uneconomical. If, on the other hand, the frequency is too low, failure can occur before the scheduled preventive maintenance time. An optimal preventive maintenance schedule requires 'trial and error' experimentation.

iv. Some plants fail due to maintenance-induced defects. This mainly happens if the quality of maintenance done is below standard. Sometimes human error during maintenance induces some defects in the equipment.

v. It is difficult to introduce effective preventive maintenance on new plants because it requires some knowledge of failure trends within the equipment after some period of time in operation.

6.3.2 Advantages of Preventive Maintenance:

i. Maintenance work can be planned ahead of time and all activities scheduled and coordinated well ahead of time. This assures that all necessary resources required for the maintenance work are available before the real work starts. This results in shorter maintenance time, and thus greater cost effectiveness.

ii. Many problems can be arrested before they occur, thus reducing the embarrassment of an unexpected plant failure. In that case, it increases the plant's reliability.

iii. Plant productivity can be highly increased by good coordination between the production and maintenance departments. This reduces conflicts on priorities between the production and the maintenance activities. Also, the downtime can easily be coordinated and managed.

iv. A good preventive maintenance system can lead to better spare parts management. The amount of spare parts required within a year can easily be worked out from the preventive maintenance plan. This will result in better spare parts control and, thus, reduce unnecessary inventory.

v. Except for critical elements requiring continuous operation, less standby equipment will be needed. With an effective preventive maintenance, there is no need for standby equipment as the plant will be in good operating condition at all time. Preventive maintenance is carried out before any failure has occurred.

vi. Less labour requirement for a preventive maintenance system, since the system result in optimum utilization of labour. Also, since preventive maintenance is scheduled, there is less overtime work required and so is more cost effective. Hence, preventive maintenance is a very important management tool, especially given the new trends in labour attitudes against working overtime.

6.3.3 Implementation of Preventive Maintenance:

6.3.3.1 Selection of Equipment for Preventive Maintenance:

The following criteria may be used in selecting equipment for regular preventive maintenance:

i. Cost: The overall cost of preventive maintenance should not exceed the total cost of breakdown repair and the cost of lost production. A formula which can be used to determine whether preventive maintenance is cost effective is [33]:

$$PM=D(A+B+C)/(E \times F) \quad \ldots\ldots \quad 6.1$$

where: D is number of breakdowns/year;

A is cost of breakdown;

B is the cost of lost production;

C is the cost of repairing other equipment involved in the breakdown;

E is the cost of PM activity (average); and,

F is the number of PM cycles/year.

If failure of the equipment will cause excessive loss in production and restoration of the equipment may take too long time to be tolerated, then it is important to introduce preventive maintenance. But, the cost of preventive maintenance should not exceed the cost of the equipment. It will be uneconomical to spend lots of money to inspect and maintain a part which can be replaced at insignificant cost, and would not affect production in case of failure.

ii. Safety: Preventive maintenance should be enforced in elements whose failure will endanger the personnel and/or integrity of the system. Preventive maintenance should also be implemented to elements whose failure will cause a secondary failure, that is the failure of the element will induce failure in other element(s).

iii. Government regulations: In some equipment, failure may be disastrous to either personnel or environment. In those types of equipment, it is required by government regulations to do a regular preventive maintenance, and to keep a log-book of maintenance work done.

iv. Insurance need: If some of the equipment is insured, then it is required by regulations to keep the equipment in good operating condition, and to do a regular inspection so as to qualify for compensation in case of accident.

v. Failure cost: In some equipment, when failure occurs, the equipment that is associated with the defective component may be destroyed. If the defective component is changed before the failure occurs, the equipment won't be damaged. In this case, it is necessary to introduce preventive maintenance so as to save the equipment.

6.3.3.2 Steps in Introducing Preventive Maintenance:

i. Wireman [34] suggests that to start with areas which will give the quickest, most noticeable, and maximum pay-off, it should be the area where the problem is irritating to both maintenance and production personnel, and then make a program for the area. If all effort will be concentrated in that small area, good results will be seen in a very short time. But, this area should not be critical area in plant operation, because if anything goes wrong, then all the merits of a good preventive maintenance system will be overlooked. Implementation of preventive maintenance for the whole plant is not an easy and short time plan, so it will be easier to convince management, and the other maintenance personnel, to introduce a preventive maintenance for the whole plant by starting with a small part of the plant.

ii. The second step is to gather all of the manufacturers' information about the equipment. This information includes: operating and maintenance manuals; recommended spare parts; special tools required; and, any other recommendation from the manufacturer. It is also important to gather equipment information from the site, such as serial numbers and instrumentation settings, and compare the information with the information from the manufacturer. This will help to prove that the information which is at hand is the same as the information from the field.

iii. Review the records of faults observed, repair work done on the equipment and their frequencies. If there is no record kept, it is important to start record keeping immediately. The record should show: equipment number and location; accumulated time to failure; type and number of failures; corrective action(s) taken; type and amount of spare used; downtime of the equipment; cost of repair; and any other type of information which is unique to the company.

iv. A list of available resources from the maintenance departments is also very important. This list should include skilled personnel in the maintenance group and their area of expertise. By knowing the skills of the maintenance personnel, the assigning the responsibilities will be simplified. This will also assist in identifying whether there is a need for training the maintenance personnel or not. It is also necessary to have a list of test instruments, such as feeler gauge, vernier callipers, etc., and maintenance tools, such as spanners, pullers, and other devices. By making the list of test instruments and tools, it will be possible to identify any important missing tools or instruments, and hence helps to identify types of maintenance actions which cannot be done by the maintenance crew within the company.

v. Failure data may be collected while doing inspection, servicing, or just from the normal production operation. The frequency of occurrence, and the cost incurred in rectifying each failure should be recorded. The information is useful in doing Pareto failure analysis which in turn, will be useful in identifying areas which need more attention than the other. In addition, it will be easier to sell the preventive maintenance program to management if the total failure cost is presented as a percent of the total revenue.

vi. When performing failure analysis, the Weibull graphical method may be used to determine whether the failure rate is increasing, decreasing, or is constant. This will assist in identifying the nature of failure and in scheduling preventive maintenance actions before the next failure. From failure data analysis, it will be possible to design a preventive action for each piece of equipment to about 80% accuracy. For each piece of equipment, make a list of tasks which will be done during each preventive maintenance activity. This tasks may be broken down to show duration, type of spare parts needed, type of tools needed, type of skills needed, etc..

vii. Make a weekly, monthly, and at last a yearly schedule for plant and equipment inspections and services. This schedule may be based on hours of operation, mileage, cycles, or just be based on days, weeks, months, etc., elapsed since the last inspection. Services are the activities that are performed periodically so as to make sure that the equipment is at a proper operating condition. Service work may include the following activities: oil change, lubrication, replenishing of consumables, minor adjustment such as tightening of loose components, and replacement of short life spare parts. Service activities also include cleaning of permanent filter and other machine parts which are subject to contamination, such as lubrication nipples.

In many situations, maintenance inspections normally accompany the regular servicing schedule of the equipment. Maintenance inspection involves the process of examining the equipment for any change in designed performance, component wear (dimensional change), too much clearance (which cause 'part-play'), misalignment, oil level, overheating, loose connections, etc., and determining the extent of work required to rectify the situation to its normal operating condition.

Inspection may be carried out by a trained artisan or technician, maintenance foreman, production foreman, or a specialized engineer depending on the type of inspection and the complexity of the inspection task itself. Inspection can be done using simple equipment, such as feeler gauges to measure clearances, callipers to measure wear, industrial thermometers to measure overheating, proximity transducers to measure misalignment, or just visual inspection by experienced personnel. More specialized inspection needing the signature of qualified personnel, such as boiler inspection (e.g. boiler temperature using pyrometers, boiler pressure relief valves, etc.), must be done by well-trained personnel in that area.

Inspection reports should be reviewed at least once per week so that proper actions can be taken as early as possible. This may involve re-scheduling of the normal preventive maintenance schedule thereby affecting various departments. Proper co-ordination between departments affected by the re-scheduling of the preventive maintenance schedule is very important at this stage so as to avoid conflict over different priorities between the departments. Inspection reports should be made available to other departments which will be affected. The reports should be concise, specific, and understandable to all who will read them. The use of inspection cards with prompt questions, and possible answers will help to standardize the inspection procedure and as a result will produce a report with the same type of format.

viii. Make a spare parts list including consumables and replaceable spare parts, preventive and emergence maintenance spare parts, etc.. In that list, availability of the spare parts, whether within, or, from outside the country, should also be included. Maintenance manuals from the manufacturers are the best source of spare parts information, especially for new equipment. Whenever the company purchases new equipment, it is recommended to purchase the spare parts of that equipment, which will last for at least one year from the purchase and commission date of the equipment. For old equipment, if there are records for all maintenance work done, they will show which spare parts are being consumed and, hence, which parts to order. Red tapes discussed in section 3.9.3 should be taken into consideration whenever a request to purchase spare parts from abroad is sought.

ix. With cooperation from the production department, assign the downtime to each preventive task and make a master schedule for the year which breaks down the tasks by month, week and even by day if possible. This master schedule should be reviewed as frequently as possible after completion of each task. A comparison should be made for the planned downtime and the real downtime after completion of each task.

x. Lastly, a strict follow-up of planned activities is very important for the effectiveness of the system and maintenance activities are no exception. Top management support is very important especially when there are priority conflicts or misunderstandings between the maintenance and production departments. The support is also important in order to give moral support for the new system.

6.4 Condition Based Maintenance (CBM):

Condition based maintenance is a type of maintenance whereby a piece of equipment or part of it is constantly monitored to enable its condition to be known, and so that any incipient deterioration and faults can be detected early enough so that proper actions can be taken to stop a total failure. Incipient faults are diagnosed to establish the real cause of malfunction, and can be established when it will be still safe to operate the plant without failure. By condition monitoring it is possible to establish the trend of the equipment data, and by using the statistical and probability theories, it is possible to predict the future condition of the equipment.

Condition based maintenance is an attempt to obtain the advantages of preventive and breakdown maintenances without suffering their disadvantages. For example, condition monitoring will replace planned maintenance by dismantling, thus saving downtime, labour, and avoiding the potential danger of careless work and incorrect reassembly and also will utilize a component to its optimum life as is the case with breakdown maintenance. In this case and others, condition based maintenance achieves both the objectives of preventive and breakdown maintenances while at the same time avoiding their respective disadvantages.

Plant diagnosis is analogous to a medical approach of identifying a malady by studying and understanding one or more of its symptoms in that, for condition monitoring techniques, different symptoms of a plants' malfunctions are diagnosed to determine the real cause of the malfunctions. Diagnosis of plants' condition can be divided into three steps as described in figure 6-2 [35]: signal sensing; processing of the sensing; and, identifying the cause.

The first step is to detect the signal by different techniques (such as vibration, temperature, and noise) to identify the signal from the plant under test. The signal can be at any state, provided that it gives the indication of the health of the plant.

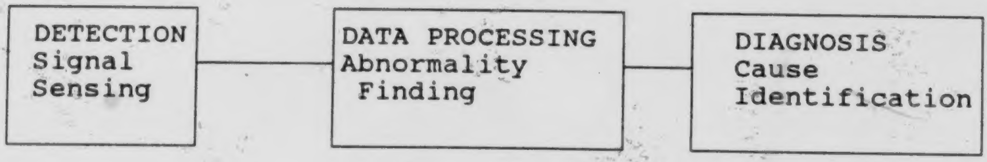


Figure 6-2: Three Steps of Plant Condition Monitoring.

The second step is to analyze the signal(s) obtained. This may involve statistical analysis, trend analysis, system theories, or any other analysis. The third step is to identify the cause of the malfunction from the analysis in step two. The important thing in this third step is to identify the origin or the precise cause of the failure.

6.4.1 Thresholds:

In order to profit from a good condition based maintenance system, it is important to make a control chart for each piece of equipment (figure 6-3). Most manufacturers normally run equipment until failure in their laboratories as part of their tests to evaluate quality, reliability, maintainability, and maintenance procedures [36]. These data may be utilized to create the control charts. However, it is important to collect data from the actual operation condition in order to determine how much stress can be put on a device before failure will occur. To set a threshold, it is important to get measurements just prior to or at the time of failure. The next step is to set a warning limit at which time action should be taken so as to avoid a total failure. For some equipment there is a lower and upper threshold while the normal operating condition is between these two thresholds.

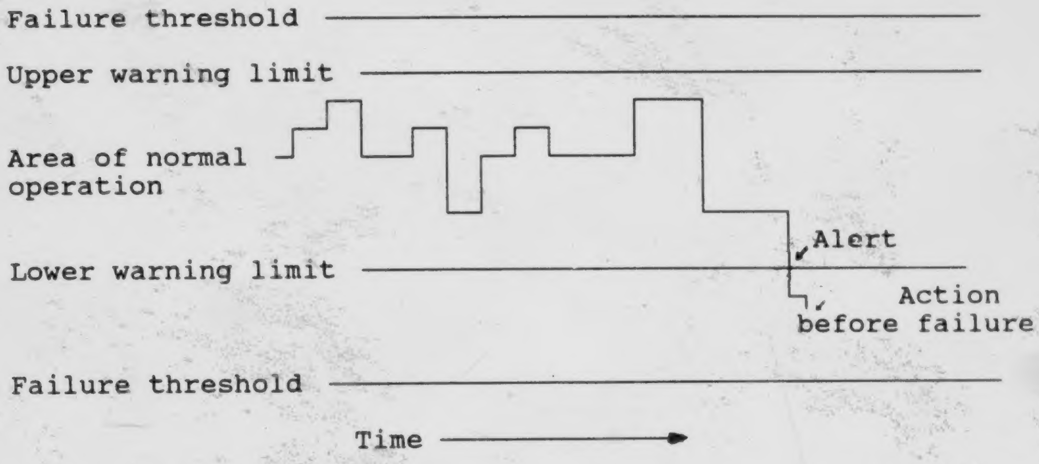


Figure 6-3: Control Chart

6.4.2 Disadvantages of Condition Based Maintenance:

i. Condition based maintenance is applicable only to machine components with a gradual type of failure, thus it cannot be applied to a component with a sudden type of failure. For example, it is almost impossible to set a monitoring device for most electronic devices, since the type of failures they experience is usually abrupt and without any previously noticed signals of failure. In this type of equipment, it is better to make a plan for trouble shooting so as to minimize downtime rather than trying to monitor the components.

ii. The monitoring equipment itself can lead to an increased level of plant failure. This will reduce the reliability of the plant and increase its downtime. Therefore, the reliability of a monitoring device must be higher than the reliability of the equipment to be monitored. It has been suggested that the reliability of the monitoring device should be at least an order of magnitude higher than the monitored machine component [37] and its failure should not cause component failure.

iii. False alarm of the monitoring device can lead into a false action. In some cases a monitoring device can show that there is a failure in a component, while the component is alright, or showing that the equipment is okay while there is a failure. A catastrophic failure can occur if the monitoring device itself fails. Once a monitoring device is installed, it is assumed that it will function properly, and normally the operators tend to trust the device to an extent that they stop to make a routine check up of the equipment. In that case, if the monitoring equipment malfunctions, nobody will notice till a failure has occurred. Thus, it is important that the monitoring method should show its own malfunction. It should not deliver the same type of alarm as for the failed equipment as this may lead to incorrect action. The failed monitoring device must give an alarm which is quite different from an alarm which indicates equipment failure so as to avoid ambiguity.

v. Most of the monitoring devices can only show that there is a failure in the equipment, but they cannot show which part of the equipment has failed. For example, vibration analysis can show that there is a misalignment, oil whirl, imbalance or bearing failure, but, this method cannot show exactly which part of the equipment has failed. In that case it is necessary to have more than one device to indicate the failed component.

vi. Some of the monitoring devices are too expensive to be used by small firms. From an economical point of view, it is better to use ordinary preventive maintenance, or apply breakdown maintenance rather than using some of the monitoring devices.

6.4.3 Advantages of Condition Based Maintenance:

i. An optimum maintenance can be obtained through condition based maintenance. In condition based maintenance, maintenance work is carried out only when it is necessary to not deliver the same type of alarm as for the failed equipment as this may lead to incorrect action. The failed monitoring device must give an alarm which is quite different from an alarm which indicates equipment failure so as to avoid ambiguity.

v. Most of the monitoring devices can only show that there is a failure in the equipment, but they cannot show which part of the equipment has failed. For example, vibration analysis can show that there is a misalignment, oil whirl, imbalance or bearing failure, but, this method cannot show exactly which part of the equipment has failed. In that case it is necessary to have more than one device to indicate the failed component.

vi. Some of the monitoring devices are too expensive to be used by small firms. From an economical point of view, it is better to use ordinary preventive maintenance, or apply breakdown maintenance rather than using some of the monitoring devices.

6.4.3 Advantages of Condition Based Maintenance:

i. An optimum maintenance can be obtained through condition based maintenance. In condition based maintenance, maintenance work is carried out only when it is necessary to do so; 'if it works, don't fix it'. This results in an overall reduction on maintenance costs.

ii. Impending failure can be predicted far away up stream, thus with effective condition based maintenance, there is no need for a standby plant.

iii. Condition based maintenance increases plant availability and reliability due to reduction in both planned and unplanned downtime. In comparison to regular preventive maintenance, for condition based maintenance, maintenance work is done only when it is necessary to do so. This reduces the problem of over maintenance found in the regular preventive maintenance. Condition based maintenance eliminates the problem of unnecessary shutdown of the plant.

iv. The ability to detect incipient faults makes the condition based maintenance the safest maintenance system. In regular preventive maintenance, failure can occur due to internal defects even in very new components which have just been installed. With condition monitoring systems, these defects will be detected. For critical equipment, the monitoring device should be able to indicate the symptoms of failure at the earliest stage when it is still safe to operate the equipment.

vi. Condition based maintenance increases confidence and motivation to maintenance personnel: they know the reason for maintenance; and it is easier to convince the management of maintenance activities and costs.

6.4.4 Condition Monitoring Techniques:

A monitoring system for a particular plant may involve the use of a single technique or a wide range of techniques. The following are among the techniques known: human senses; visual inspection; fibre optics; acoustic emission; ultrasonic detection; oil debris analysis (spectrometric and ferrographic analysis); lubricant film thickness; vibration analysis; dimensional analysis; temperature measurement; alignment measurement; power consumption analysis; position detectors; strain measurement; and, electro-optical laser system.

The prices of condition monitoring equipment varies from simple sensors and transducers, such as limit and speed switches which costs less than $100, to the highly sophisticated 'Computer-Based Acoustic Emission Analyzer' which costs about $100,000. Typical prices of various monitoring device are shown in appendix 5.

6.4.4.1 Human Senses:

Before development of the present time sensors, experienced human beings have used their senses of sight, sound, smell, taste, and touch to detect incipient failure of equipment. Experienced technicians could detect a defective equipment by detecting either a change in its noise, temperature, or vibration. Effort could be put to increase the sensitivity of human senses to detect unusual changes in the work environment. The experience of well-trained maintenance personnel could be accompanied by a standardized device, such as simple meters, to increase the accuracy of detection.

Training of machine operators in this area is most important, because the operators are the ones who are in daily contact and more familiar with the machines than are the maintenance personnel. Also, for this system to be effective, it is important to have a single operator per machine, so that the operator will be accustomed to the machine to an extent of being able to detect any change in the normal operating characteristic of the machine. For example, an experienced bus driver will be able to detect any abnormality with the bus, if he/she is used to drive the same bus for a certain period of time. However, this system is difficult to implement for a multi-shift operation in which different operators have to use the same machine. Also, human senses are able to detect only large differences and disparities from the normal operating characteristics; normally human beings are not sensitive to small changes. Thus for small changes, other type of sensors are needed to supplement human senses.

6.4.4.2 Fibre Optics:

By using the advantage of fibre optics, it is possible to diagnose the internal structure of a component. Fibre optics has wide application in medical sciences, in which it is used to observe the internal organs of human beings, such as the intestines. The potential use of this technology is not yet fully applied in engineering sciences, especially in maintenance management. This technology could be applied in detection of internal cracks in many pieces of equipment and other internal failures such as pitting, build up of foreign materials (e.g. build up of salts in pipes), etc. Even a component which has a winding internal structures, such as muffler, pipes, water jackets in engine housing, etc., can be diagnosed using the fibre optics technique. This technology could be used in diagnosing the internal parts of the engine without dismantling the whole engine, such as monitoring the clearances in the cylinders, and monitoring the condition of the journal bearings in the crank shaft.

6.4.4.3 Temperature Measurements:

Normal operation of any relative moving parts generates heat, which causes a rise in temperature. By monitoring the temperature of the part(s), it is possible to generate the normal characteristics of a healthy operating equipment. For example, the average bearing operating temperature is between 40 and 50 °F above the ambient temperature surrounding the bearing [38]. If, in any time of operation, there is a deviation in the temperature of the equipment, then it is symptomatic of a problem within the equipment. This technique, to be profitable, needs constant observation of the equipment. An automatic monitoring device could be installed which should be able to give an audio or visual alarm whenever the temperature of the equipment is beyond the normal operating temperature. However, intermittent temperature recording is also recommended in areas where a continuous monitoring would be too expensive to be economically viable. This could be done with an assistance from the machine operators. The technique could be applied to monitor the temperature of the bearings, cooling water, lubrication oil and other parts which generate heat. One of the devices which can be used to monitor the change in temperature is an infrared thermograph. This device can be coupled with other device to transform the heat energy into electrical energy, which can be then connected to an audio or visual alarm.

Other instruments used for temperature analysis of equipment include simple devices such as thermocouples, heat sensitive paints, industrial thermometers, pyrometers, and temperature transducers. Hence, temperature measurement is among the cheapest condition monitoring techniques. The price of a thermocouple is only between $100 to $500, while that of an industrial thermometer is less than $200.

A hand-held digital thermometer (figure 6-4) is among the simplest devices used to measure bearings' temperature. The thermometer is equipped with a probe that can be inserted into the grease hole in a bearing housing until it comes into contact with the outer ring of the bearing [39]. This thermometer gives a more precise bearing temperature than other thermometers which simply measure the outside housing temperature of the bearing.

Figure 6-4: Hand-held Thermometer

6.4.4.4 Vibration Analysis:

This is among the simplest and most widely applied condition monitoring techniques. It is mostly applied in a rotating machine, like monitoring the bearing vibrations in an electrical motor. Vibration monitoring involves the attachment of an accelerometer to a machine to record its acceleration. Accelerometers are usually permanently attached to equipment at 90° apart and perpendicular to the rotating axis [40]. Measurement may be taken by a portable test meters and chart recorders, or by permanently attached recorders or transducers. Acceleration measurement is usually applied in high-speed rotating machines.

Other techniques of measuring vibrations include measuring the (peak-to-peak) displacement, which is used in low-speed machines, and the velocity (speed at which displacement takes place). Vibrations may be either of horizontal or vertical nature, or combination of the two. Special equipment is required to indicate the nature of vibration (horizontal, vertical or combination of the two), the problem (misalignment, oil whirl, bent shift, etc.) and, if possible, its precise cause (the cause of the oil whirl, the cause of misalignment, etc.). This may involve the regular monitoring of vibrations in the equipment and detection of any increase in vibrations of the equipment. In gas or oil transmission, it includes measurement of piping pulsation from the reciprocating engine and analysis of effects of pulsation on orifice flow measurement at the meter stations. In modal testing, natural and critical vibration frequencies are measured when a known vibration is induced.

Increased vibration may be caused by a number of factors such as misalignment during overhaul; incorrect shaft or housing fit; foreign matter in bearing; rotor cracks or bends;

imbalance; oil whirl; improper bearing housing; and, foundation problems. So, it is very difficult to tell exactly what the problem is by vibration analysis alone. Vibration analysis may be backed up with visual inspections and other measurements such as bearing oil pressure, bearing temperature, gas in insulating oil, etc. in order to be sure that the cause of increase in vibration is within the bearings or is caused by something else.

Machinery vibration testing can be performed either on site measuring the entire equipment or can be done in a laboratory by testing its major and/or auxiliary components. This can be accompanied by in-depth spectrum analysis of the equipment. In addition to accelerometers, other vibration monitoring equipment include vibration meters which are mainly portable (figure 6-5) [41], these can be used to take readings at certain regular intervals, and a resulting graph of vibration versus time can be plotted. Using control charts, when the vibrations have reached a warning limit indicating a certain wear within a component, then the component can be changed before failure occurs. An advantage of a portable vibration meter is its application even in the most remote areas.

Another type are the vibration transducers which are often permanently installed on the equipment (figure 6-6) [42].

University of Alberta

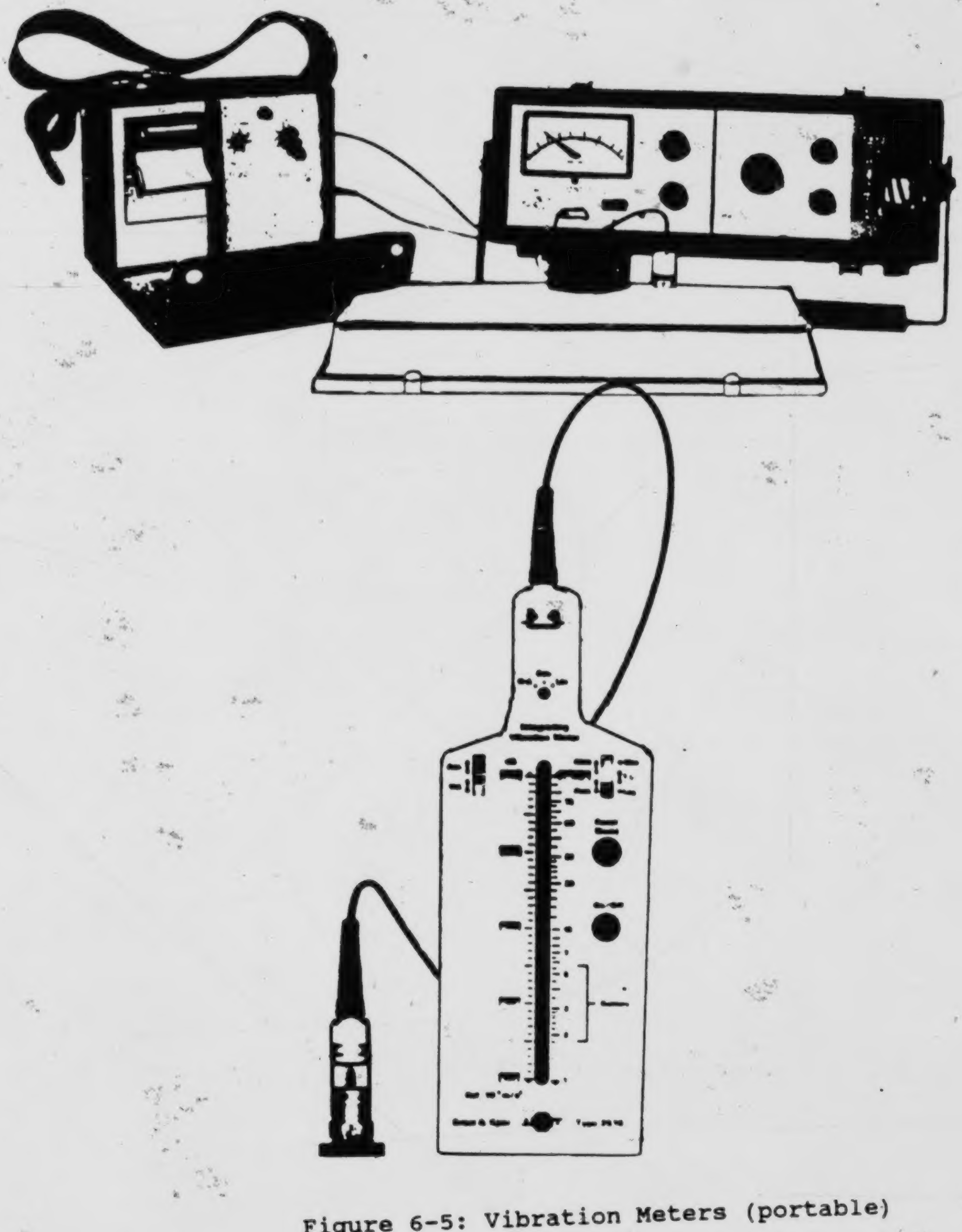


Figure 6-5: Vibration Meters (portable)

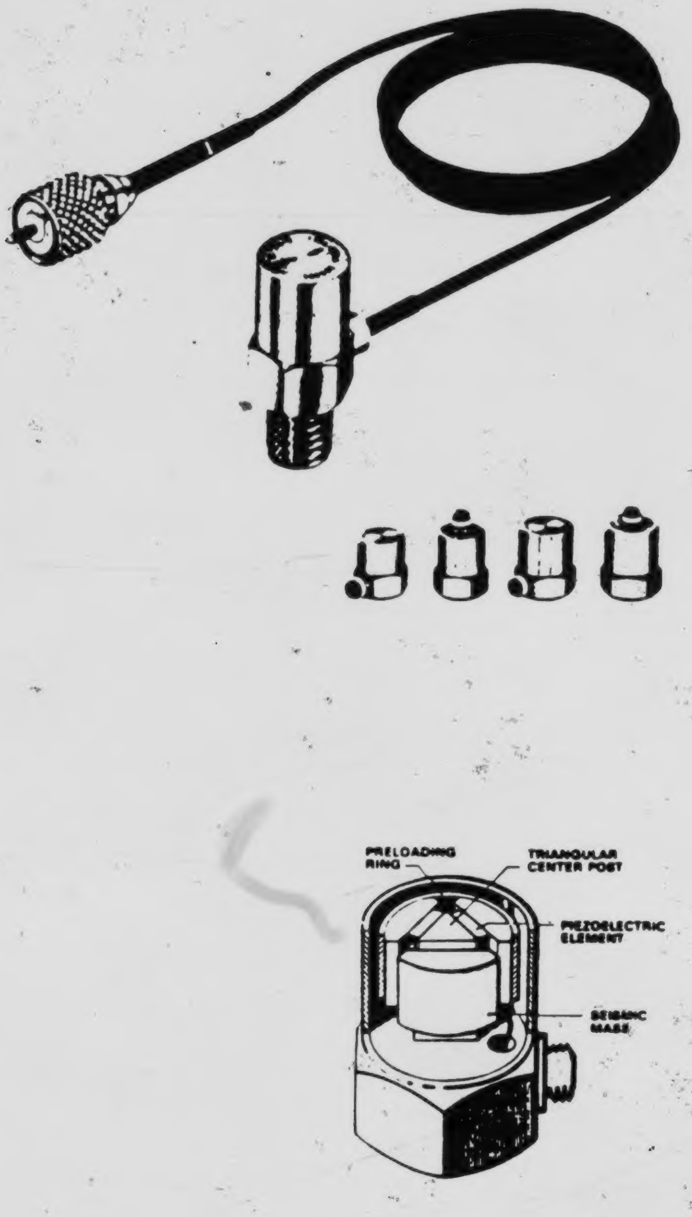

PRELOADING RING
TRIANGULAR CENTER POST
PIEZOELECTRIC ELEMENT
SEISMIC MASS

Figure 6-6:Vibration Transducers (Permanently installed)

These permanently mounted transducers are more accurate than the portable ones; since changes in vibration do not depend on time, higher vibrations can occur at any time in which, and some of the peaks might be missed with the portable vibration meters. Using these types of transducers, one control room can be used to feed and receive signals from several transducers. The signals can be fed directly to a computer and a plotter, which is more economical than manual recording and plotting, especially when there are a number of pieces of equipment to be monitored.

6.4.4.5 Oil Debris Analysis:

This is an analysis of impurities in lubricating oil. Whenever there is wear in a lubricated machinery part, the particles are carried by the lubricating oil. Therefore,

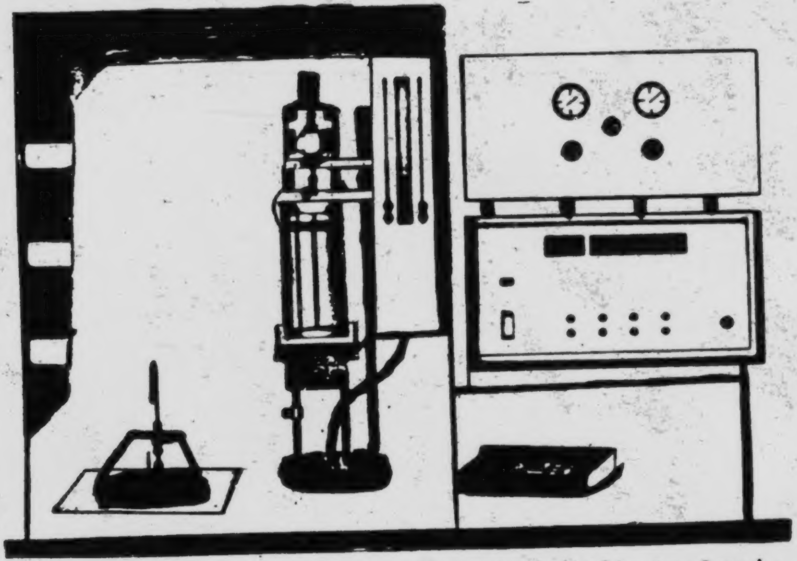


Figure 6-7: Spectrometric Oil Analysis Unit

detection of the number of particles, their sizes distribution, chemical constituents, shape, etc. is a very useful tool in condition monitoring. Various techniques are used to detect the above properties of debris in lubricating oil.

Among the techniques used are magnetic plug inspection, and spectrometric oil analysis. In spectrometric analysis (figure 6-7), the task is to analyze the type of material the particles are made of. The particles may be dirt, wear materials, or additives which have solidified. If the particles are just dirt, all that is required is filtration or changing of the oil. But if the particles are made of wear materials, the second step is to determine the component in from which they come [43]. The amount of particles is a direct measure of the amount of wear. If the wear is excessive, the component should be removed or repaired before breakdown occurs.

For measurement of ferrous particles in lubricating oil a ferrograph is normally used. Ferrographs precipitate ferrous particles from the oil sample and give the number of the particles and their size distribution in the oil. As with spectrometric analysis, the number of particles indicates the amount of wear in a material.

6.4.4.6 Lubricant Film Thickness:

Lubrication film thickness can be utilized to measure the lubrication condition in a bearing and, hence, to analyze the incipient damage in a bearing. The importance of the lubrication film thickness is mainly for its comparison to the average surface roughness of the bearing [44]. This will assist in analyzing the mechanical condition of the loaded area of an operating bearing's rolling interfaces, degree of lubricant starvation in the bearing and the extent of damage caused by the lubrication starvation. This is important in determining the lubricant type, optimum lubricant flow, time period for lubrication, mechanical deterioration in bearing and, therefore, the remaining bearing life.

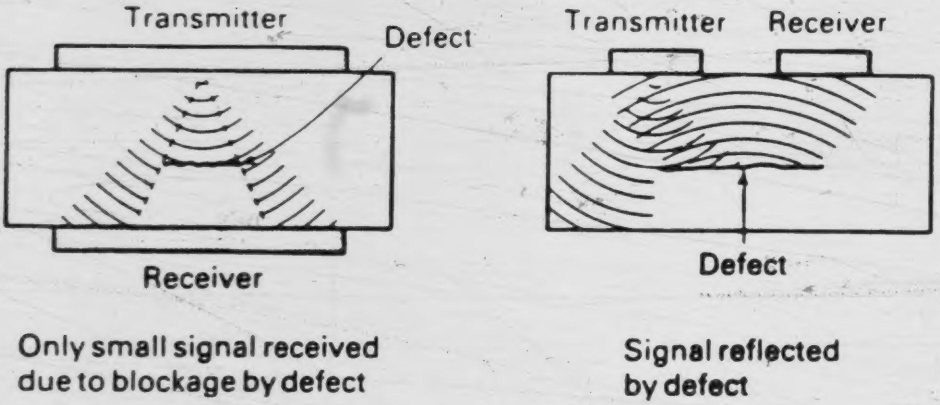
Different methods can be used to determine the lubricant film thickness, but the most commonly used is the shock pulse method. When the surface asperities in the rolling elements in bearing interacts, they generate stress waves of ultrasonic nature [45]. These stress waves are the so called shock pulses and can be detected by a piezoelectric transducer. Shock pulse measurement is a direct image of the random interaction between the surface asperities in the rolling interface. Lubricant film in the rolling element of a bearing is responsible for carrying the load and thus can be treated as part of the bearing. Therefore, even if the rolling interface is completely separated by a lubricant, shock pulses will still be generated. Hence, shock pulse can be used to measure the lubricant film thickness in any state of lubrication in a rolling element of the bearing.

6.4.4.7 Sound and Ultrasonic Analysis:

Ultrasound is sound wave which is above the hearing range of a human being (20 Hz to 20 kHz). Ultrasound occurs above 20 kHz and the range of airborne ultrasonic detection is between 20 kHz to 100 kHz [46]. Sound is generated when a vibrating body causes air particles to vibrate for a short distance. The air particles transfer sound energy from one another when they vibrate in an alternating chain of a sound wave. This sound energy can be measured by its amplitude of vibration (i.e. amplitude of the wave) and intensity.

Ultrasonic scanning can be used to detect pressure and vacuum leaks, locating faults in valves, condensers, gaskets and seals. Also, it can be used for troubleshooting compressors, pumps, heat exchangers, steam traps, tanks, turbines, boiler casings, detecting mechanical wear in gears and finding loose connections in electrical systems. The integrity of electrical systems can be tested by sweeping an ultrasonic detector over the test equipment so as to reveal loose connections and other openings which force the current to jump a gap [47]. Arcs (e.g., arcing at switches, circuit breakers, junction boxes, transformer, etc.) are generated whenever there is a gap and electrical current jump.

Ultrasonic testing is applicable in both condition based preventive maintenance and in quality control. Industries which manufacture heavy, thick material can use ultrasonic scanning to determine any hidden flaws, such as internal air cavities, without damaging the material under test. The ultrasonic test will give mainly two results: the thickness of the object and any subsurface flaws in the material. Depending on the type of equipment used, a visual picture of the type of defect may be available [48].



Only small signal received due to blockage by defect

Signal reflected by defect

Figure 6-8: Ultrasonic inspection

For condition based maintenance, ultrasonic testing can be used to detect subsurface defects from fatigue, corrosion or latent manufacture defects. Fatigue cracks can be detected at an early stage and the situation rectified before total failure has occurred. Ultrasonic inspection involves four steps [49]: a) affixing the transmitting unit on the test material (figure 6-8); b) fixing the receiver on the other side of or beside the transmitter depending on the type of transmitter and the material under test; c) actuating the transmitter; and d) Receiving the signal back.

6.4.4.8 Acoustic Emission:

Acoustic emission is a technology which describes the generation of transient stress waves by materials in distress. Incremental crack growth and dislocation mechanism can both generate transient stress waves (AE) from the sudden release of localized stored elastic energy [50]. Acoustic emission is a low level, transient stress wave which emanates from a growing defect or flaw [51]. The growth of the flaw/crack creates a stress wave which can be detected by piezoelectric transducers and electronic signal conditioners. Acoustic emission technology can be applied to detect the following plant failures:

a) Shaft alignment;
b) Bearing deterioration;
c) Loss of grease or lubrication;

d) Contamination of lubricant;
e) Cavitation in pumping installations;
f) Excessive wear on driving gears;
g) Plant mechanical looseness;
h) Coupling defect and seal leakage;
i) Fluid, gas and steam leaks; and,
j) Piping misalignment and stressing [52].

Also, acoustic emission can provide continuous monitoring of a plant. This will include: a) manual routine inspection surveillance; b) continuous analogue monitors and alarm; and, c) computerized surveillance. For manual routine inspection, high frequency, narrow band piezoelectric transducers are permanently attached to a rotating machinery, and a portable instrument is attached to each sensor [53]. Two readings RMS (Root Means Square) and SAT (Spikes Above Threshold) are taken and recorded. With an aid of a Cathode Ray Tube (CRT) oscilloscope, detailed diagnostic display can be obtained to analyze the various signals obtained from the machine under test.

For a continuous analogue monitor and alarm, the device which consists of a number of sensors or transducers is permanently fixed to the equipment under test (figure 6-9). A pre-amplifier is mounted at least half a meter from the sensor, and a co-axial cable links the pre-amplifier to the acoustic emission monitor and alarm [54]. Readings of vibration, RMS, and SAT are continuously monitored. The monitor triggers whenever the limiting value is exceeded.

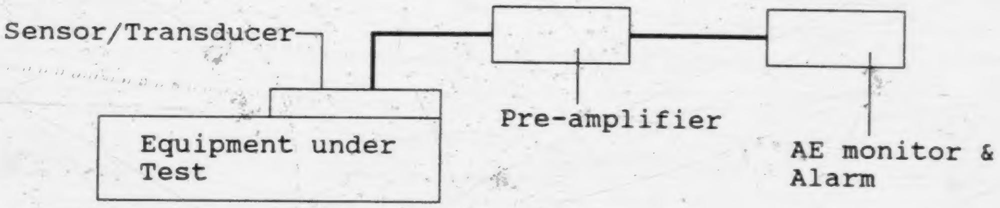


Figure 6-9: Continuous Analogue Monitor

Computerized surveillance become economical when there is a lot of data collection and analysis required making manual inspection and analysis cumbersome and uneconomical. Computer applications simplify data manipulations and presentation, data repeatability, and transducer calibration repeatability. Also, computers increase the accuracy of data reading. Computers eliminate the laborious task of data reading, data presentation and daily checkups of equipment. With the advent of high capabilities, fast, and cheap computers, it is possible to use a single computer in a multi-system data reading and analysis. This reduces the number of employees needed for data reading and analysis.

6.4.4.9 Power Consumption Analysis:

A normal operating plant has a certain optimum power consumption when it is in operation. Although power consumption is not constant, due to varying load, there is a maximum and minimum bar in which the normal plant will be operating. To be able to use this technique in monitoring the condition of the plant, it is necessary to have a continuous measurement of power consumption of the plant, for a certain duration of time, so as to be able to establish the operating characteristics of the plant. After establishing the maximum and the minimum operating power at different loads, a monitoring device is calibrated at those normal operating powers. The monitoring device should be able to give an audio or visual alarm when the set maximum or minimum power is surpassed. Power measurement differs from one piece of equipment to another. Different characteristics of equipment can be used to measure its power indirectly. Power can be measured either at the output as output power, or at the input as input power. The indirect power measurement of equipment may involve the measurement of a shaft speed n (rpm) using a boroscope or tachometer, and the measurement of torque using strain gauges, measurement of input voltage and input current.

6.4.4.10 Alignment Measurement:

Misalignment is an installation problem, whose effect is manifested in different modes in different elements of the equipment. For example, if the shaft that the bearing is supporting is not properly aligned, the bearing will wear in a pattern for which it was not designed. The bearing's rolling element will try to run in a new path, the bearing won't allow proper lubrication and loading which will result in metal-to-metal contact and, hence, rapid deterioration of the bearing [55]. Shaft misalignment can be detected by using simple microswitches or proximity detectors.

In gear drive, if the gears are vertically misaligned, there will be contact between the tip of one tooth and the root of another tooth. This will result in rapid wear of the teeth and, hence, failure. If the misalignment is off side-to-side, one side of the tooth will carry all the load, this will result in rupturing of the oil film barrier between the teeth [56]. If the misalignment is very big, the tooth will be scored to an extent that it will break off, but if it is a minor misalignment, sometimes the problem will correct itself or result in minor scoring.

There are various methods to detect misalignment in different components of a piece of equipment. Acoustic emission can be utilized to detect misalignment in shafts, piping and in bearing. But shaft misalignment can be cheaply detected by means of a displacement transducers (figure 6-10), a common method used in detecting shaft misalignment.

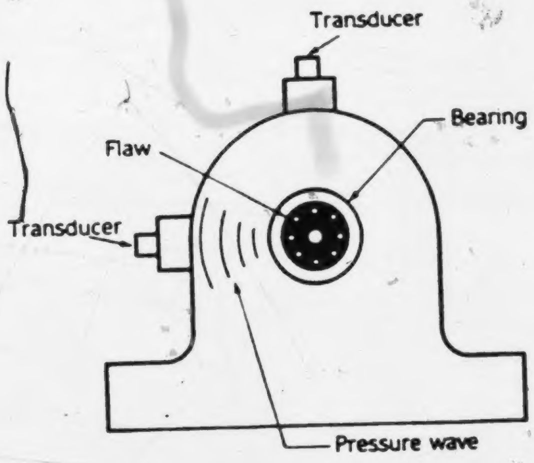


Figure 6-10: Displacement Transducer

6.4.5 Implementation of Condition Based Maintenance:

6.4.5.1 Selection of Equipment for Condition Monitoring:

The following criteria may be used for the selection of machines for condition monitoring. The first step is to determine the machine's suitability for condition monitoring (the machine must have a component which fails progressively rather than suddenly) [57]. Condition monitoring is only applicable for machine components which give a reasonable advance warning before total failure occurrence. After identifying the machine for condition monitoring, the second step is to identify the critical component(s) in the machine. All machine failures are caused by component failures, so it is important to study not only the critical component(s)' behaviour, but also the failure modes in each component under consideration. This can be done by constructing a table of all possible component failures, and assessing the following factors for each component [58]: a) the likelihood of failure; b) the consequence of failure; and, c) the repair time required. If the component is likely to fail, the failure is progressive, serious, and it takes a very long time to rectify the failure, then it is worth condition monitoring.

Cost is another consideration in selecting equipment for condition monitoring. From an economic point of view, the effectiveness of a condition monitoring system is dependent on the relative costs of the plant, the product and the plant maintenance. It has been proposed that the cost purchase and installation of a monitoring system should not exceed 1% of the value of the plant to be monitored, unless there are other priorities, such as safety and reliability, which need to be considered [59]. It would be uneconomical to use a condition monitor which costs more than the equipment to be monitored.

6.4.5.2 Selection of Appropriate Technique for Monitoring:

The condition monitoring of a component can be done using one or more techniques. The selection of the appropriate technique is critical for the effectiveness of the condition monitoring system. The first criterion in selecting a monitoring system is the reliability of the system; the monitoring system should be more reliable than the equipment it is used on. Earlier in this chapter it was suggested that mean time between failure of the monitoring system should be at least one order of magnitude better than the expected life of the monitored equipment [37]. Also, sensor failure should not result in machine failure; if the failure of the sensor induces component failure, then the monitoring system increases failures instead of reducing them.

The monitoring system should be robust enough to withstand misuse and maltreatment. In an industrial situation, misuse of equipment is common due either to lack of knowledge of appropriate usage, or just curiosity of the worker. The monitoring system should be able to withstand vibration, dropping, oil, and, if possible, should be heat resistant.

Simplicity of the monitoring system is also worth taking into consideration. If the monitoring system is very complicated, it increases the maintenance work since it will need further training for the maintenance crew on how to use the monitoring system. The monitoring system should be easy to use, to calibrate, to install and to retrofit.

6.5 Maintenance Prevention:

Theoretically, it is possible to eliminate failures by designing equipment with high reliability, a redundant element, and by doing regular preventive maintenance. However, from an economical point of view, such design and maintenance systems would be too expensive and uneconomical to afford. Exceptions are for equipment which are difficult to repair or for which failure would be fatal. For example an aircraft, once in the air, must function without failure, and an earth-orbiting satellite, once it is launched, must operate without failure. In these two and other similar cases, higher reliability is an obligation. All other equipment is designed at a certain level of acceptable reliability and safety, thus failure occurrence is inevitable. Analysis of failure identifies failure mode, failure source, and frequency of occurrence (failure rate). For a frequently failing component, which also takes a lot of time to repair, it is appropriate to consider carrying out maintenance prevention.

Maintenance prevention involves the redesign of a unit and sub-assembly, which is highly susceptible to failure, so as to reduce failures and improve maintainability. A trade-off between savings from higher reliability, ease of repair from improved maintainability, and cost of failure should be made to determine the type of modifications or improvements which are cost effective. In the analysis of failure costs, both the cost to rectify the failed component and the cost of lost production should be taken into consideration.

Another aspect of maintenance prevention is the precaution taken during the design stage of any new product. The earliest stage of any new product development is 'concept generation' - the idea generation stage, during which a product exists as an idea of an innovator. Feasibility studies, from both an engineering and a marketing point of view, is the second stage, followed by a design stage. It is during this stage that the designer must put the idea of maintainability in the product. It is possible to predict different types of failure under different loading conditions by analyzing different forces at the design stage. So during this stage, a designer can either prevent maintenance activities by designing with higher reliability components, or ease the maintenance work by designing with easier maintainable components.

6.5.1 Implementation of Maintenance Prevention:

The first step in maintenance prevention is to isolate the failure source so it can be determined where to start to re-design for improvement. The failure source is usually different from the component which has failed, although sometimes the failed component is the same as failure source. For example, misalignment of a shaft may cause bearing failure due to excessive vibrations. In that case the failure source is shaft misalignment and not bearing failure. Failure source is defined as the smallest component or sub-assembly which can be isolated, by means of failure analysis, as a source of malfunction in an equipment. The second step is to analyze whether a correction of the failure source is feasible, and whether the failure source can be corrected by just replacing the failed component or if it needs modification of the failure source. This may involve an economical analysis by comparing the cost benefits of just replacing the failed components from time to time with the cost of making a thorough modification of the failure source. Mean time to repair (MTTR) of a failed part may be taken as a criterion for improvement. By doing an analysis of time taken in each repair task and the repair time increments in the subsequent tasks, it is possible to determine a task which has the lengthiest time increment. This task can be taken as the candidate for maintenance improvement.

After the identification of various candidates for maintenance improvement, the next step is to rank the different components in order of ease of modification, the extent of modification and the time required for the modification. The ease of modification or improvement is somehow dependant on the extent of the hardware re-design required; the less the re-design required the easier the modification task. However, basic design modifications are almost impossible for products that are designed and manufactured without taking maintainability into consideration. For example, the majority of car block engines are designed without taking maintainability into consideration, such that whenever they crack, or water jackets leaks into the cylinders, the only way to maintain the engine is to discard the whole engine block. In some equipment, modification of one component requires a modification or replacement of a whole sub-assembly and modification of the sub-assembly will affect other sub-assemblies and so on, such that the whole equipment will be affected. The only improvement feasible under these circumstances is to discard the existing equipment and find an alternative equipment which is maintainable.

Hence, it is important to make a feasibility study of doing improvement maintenance for any component before starting any component modification. The study should: a) analyze whether it is possible to make any component modification without affecting the whole sub-assembly; b) analyze the inter-assembly relationships; and, c) analyze the whole equipment to find out whether it was designed according to maintainability principles.

7.0 In-depth Analysis of Selected Maintenance Problems in Tanzania:

This chapter deals with some few selected maintenance problems in Tanzanian industries. These problems were first discussed, in brief, during the questionnaire analysis in chapter 3. In this chapter, each problem is analyzed using different perspectives from those used in chapter 3. The author has previously worked with three different Tanzanian industries (Agriculture and Industrial Supply Company (AISCO); Tanzania Harbours Authority (THA); and, Friendship Textile Mills (FTM)), during his industrial practical training (PTs) as part of his undergraduate program. So, in some situations, the author used his own experience in Tanzanian industries to explain them.

However, it is important to note that each problem analyzed is very wide, hence, only the aspects which affect the performance of maintenance activities are discussed. The problems which are analyzed in-depth include: spare parts; skilled manpower; record keeping; maintenance information system; lubricants and lubrication program; maintenance organization; and implementation problems.

7.1 Spare Parts:

An unavailability of spare parts is mentioned as the main problem affecting maintenance departments in Tanzania.

However, the spare parts problem could be alleviated if people would make efforts to manufacture spare parts locally rather than depending on imported spare parts. Tanzania is having a problem of imbalance of trade, the country imports more goods than it exports resulting in scarcity of foreign currency. In that situation, the Tanzanian government has to restrict importation of goods to only those which cannot be obtained locally.

In the questionnaire analysis (refer to chapter 3), 60% out of 75%, who indicated that lack of spare parts is the main problem, showed that the problem was caused by scarcity of foreign currency. This shows that people have the mentality of finding the solution of their problems abroad instead of finding a local solution. Whenever there is a spare parts problem, the only solution available is to import the spare parts instead of making effort to produce them.

When asked why they have to import the spare parts, 55% indicated that they don't have machine tools, raw materials and technology to manufacture the spare parts; 35% indicated that they don't have foundry; and, 30% showed that they don't have heat treatment facilities (note: in Tanzania, almost each industry has its own workshop to supplement imported spare parts). Hastily looking at these responses, one can get an illusion that indeed there is a serious problem and that the spare parts cannot be manufactured locally. But, what the responses really mean is that they don't have those facilities within their own workshops. From an economic point of view, it is doubtful whether it is profitable to provide all those facilities to each company. Foundry, heat treatment facilities and other special machine tools are only useful if they are used for commercial purposes, and not in producing spare parts in an intermittent process. On the other hand, there are many engineering workshops which have the facilities, and can manufacture the badly needed spare parts. But, these workshops are under-utilized because the industrialists have more faith on imported spare parts.

A random survey in local engineering workshops made in 1987 by A.H. Mwinyi, the president of the United Republic of Tanzania [60], revealed that most of the spare parts which hitherto have been imported can be manufactured locally. After the president's survey, many local manufacturers of spare parts started to get a lot of orders, because the government increased the restriction on importation of spare parts. Just to show that there is a big potential for making spare parts locally, a survey made by the government owned newspaper Daily News Tanzania showed that, some spare parts manufacturers were disappointed even after the president's survey, because they did not receive as many orders from the industrialists as they expected.

> .... President Mwinyi observed that local workshops had a big potential for making spares. He, however, expressed concern that workshops were under-utilised because industrialists preferred imported spare parts [....] local spare parts manufacturing firms are happy to have received many orders for their products [....] the other are disappointed because they have very few orders .... [61]

So, it can be argued that the spare parts problem is somehow exacerbated by the industrialists themselves preferring imported spare parts to locally made ones. Perhaps the reason behind having more faith in imported spare parts, is the notion of 'genuine spare parts'. Most of the car dealers and some of the industrial machine dealers who also sell spare parts advertise their products as 'genuine spare parts'; they claim that genuine spare parts are only those made by the original equipment manufacturer (OEM). Although there is nothing wrong with such an advertisement in a free market economy, it may give an impression that other spare parts apart from that manufactured by OEM, are substandard.

One drawback of local spare parts manufacturers is the size of the companies; they are very small and are scattered all over the country. Except for a very few, such as Institute of Production Innovation (IPI) of University of Dar es Salaam (UDSM), National Engineering Company (NECO), and Mang'ula Machine & Mechanical Tools Company (MMMT), which advertise their products, the other engineering workshops are not well known by the public in general. Most of these companies depend on very few regular customers with whom they have established contacts through friendships.

In addition to the fact that there is not enough promotion of local spare parts in the media, there is no coordination among the local spare parts manufacturers either. Most of these manufacturers produce the spares on order basis, they sit and wait for orders from the industrialists, instead of taking the advantage of the free market to produce the spares for potential customers. It is doubtful whether any of these manufacturer do any market study to find potential customers consequently, they are sceptical to enter the market: they are unfamiliar with the size, the growth rate, and the competitors.

As indicated, the majority of industries have their own workshops to support their daily need of spare parts. Normally, these workshops supplement the imported spare parts within the company only and they don't accept orders from outside the company, except for few cases in which the workshop may be required to produce some essential spares for another company. Examples of such companies include Tanzania Railways Corporation (TRC), Tanzania-Zambia Railway Authority (TAZARA), and Friendship Textile Mills (FTM), just to mention a few among the best engineering workshops in the country. If these workshops to be full utilized, they could produce a lot of spare parts not only for their parent companies, but also for sale in the free market. The only catch is the availability of raw materials to manufacture the spare parts.

Almost all such raw material are imported; all metals which are currently used to manufacture spare parts are obtained from abroad. Tanzania has a very large deposit of iron ore, which if exploited could fulfil Tanzanian's need of iron for years. The feasibility study which has already been conducted has proved that Tanzania has iron ore of about 85 million tons of proven reserves in Chunya and Liganga in Mbeya region. A proposed 300,000 tons-a-year steel plant in Iringa region [62], could supply Tanzania with all its needs of steel for more than two centuries. The main problem is to get enough funding to build the proposed steel plant, which Tanzania has to borrow from international money market. Despite the fact that, for the time being Tanzania has to import all raw materials to manufacture the spare parts, if detailed study is conducted it will prove that, it is cheaper and easier to import the raw materials and manufacture the spare parts locally, rather than importing the already made spare parts.

Availability of machine tools to manufacture the spare parts is no longer a problem, although 55% of respondent indicated that unavailability of machine tools to manufacture spare parts was the problem. Kilimanjaro Machine Tools

Manufacturing Company (KMTMC), which started production in 1986/87, manufactures conventional machine tools locally. The company is built with a capability of producing 400 types of machine tools in collaboration with a Bulgarian firm [63]. Conventional machine tools such as lathe, milling machine, drilling machine, shaper, etc., can now be obtained within the country using local currency. The only problem now is to raise enough capital to purchase these machine tools, and no longer their availability.

For other problems such as the unavailability of foundry and heat treatment facilities, the companies concerned could use the few available foundry and heat treatment facilities in the country to make their spare parts. Foundry facilities are found in NECO, TAZARA, TRC, FTM, and the UDSM-Faculty of engineering (FoE) workshops. NECO has the largest and most modern foundry among those mentioned above, and in addition to a number of spare parts the workshop produces for many companies, it also produce some original parts for valmet tractors which are being assembled in Kibaha, Tanzania. The material laboratory in UDSM-FoE has heat a treatment facility which is not only for teaching and research, but also for consultancy purposes, hence the laboratory is open to the public in general. So, spare parts manufacturers and industrialists, could use this facility for their heat treatment needs at a reasonable fee.

7.2 Skilled Manpower:

According to the questionnaire, unavailability of skilled manpower is mentioned as the second major problem with maintenance in Tanzania; 70% of the replies showed that the low level of skilled manpower is one of the contributing factors to maintenance problem. Analysis of the questionnaires, shows that 40% of those who replied did not have engineers and 10% did not have even a single technician in their maintenance departments. 'Skilled' personnel in the technical field, in the Tanzanian context, must have at least three years of training from a technical college and have graduated with a Full Technician Certificate (FTC) (so technician is the lowest level of skilled manpower). In this section, the education system in Tanzania (only in the technical career path) will be reviewed with a purpose of finding out the cause of the unavailability of skilled manpower in Tanzanian industries.

The Tanzanian education system can be portrayed as a five stage pyramid, with the first stage as a pre-primary education, which is conducted in nursery schools, and the second stage being a seven year compulsory primary education. Nursery school is an optional education, and mainly found in towns and cities, while primary education is compulsory for all Tanzanian children. The pyramid of education in Tanzania is shown in figure 7-1, showing only the career path for those who intend to pursue technical education.

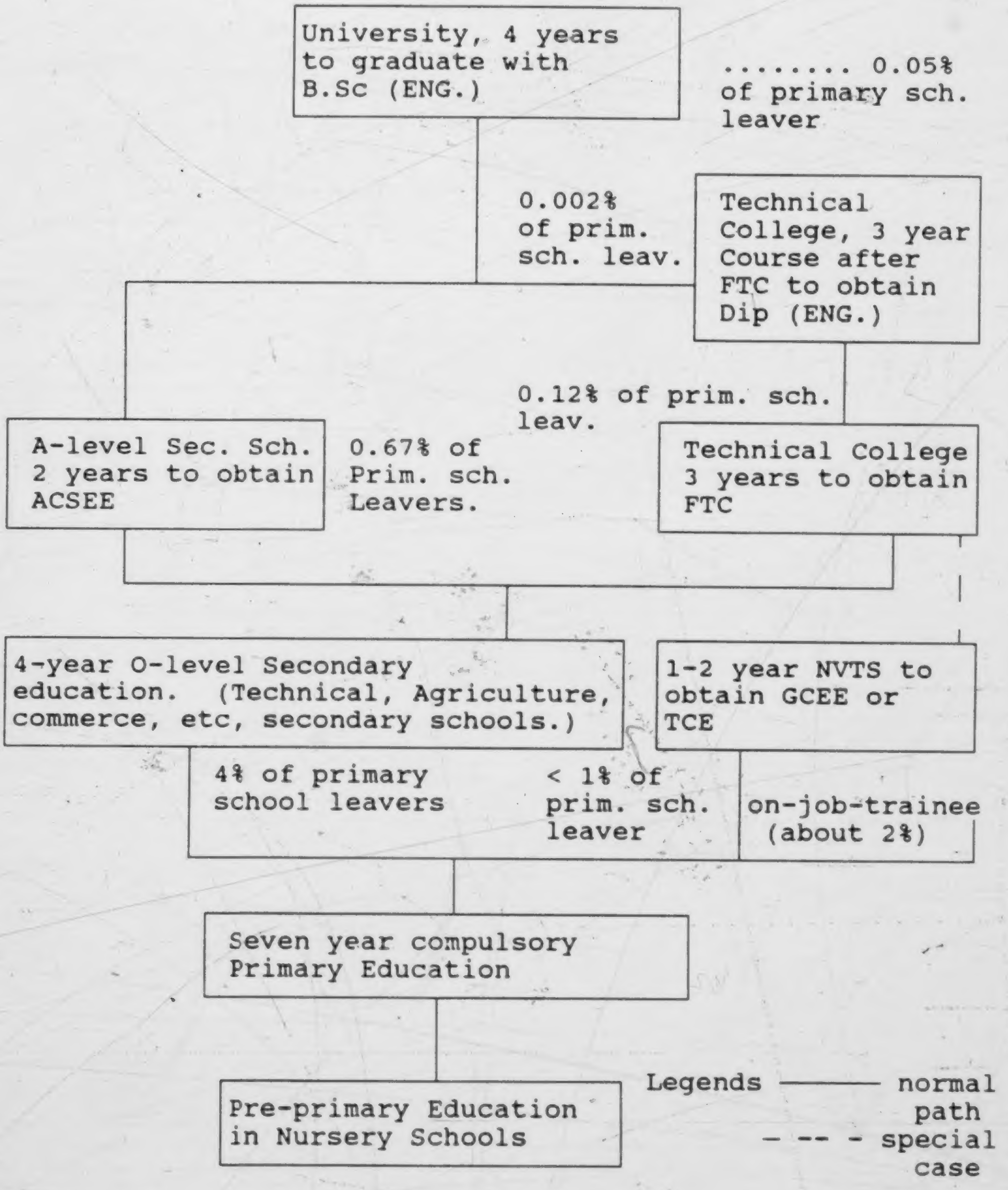

University, 4 years to graduate with B.Sc (ENG.)
.... 0.05% of primary sch. leaver
0.002% of prim. sch. leav.
Technical College, 3 year Course after FTC to obtain Dip (ENG.)
0.12% of prim. sch. leav.
A-level Sec. Sch. 2 years to obtain ACSEE
0.67% of Prim. sch. Leavers.
Technical College 3 years to obtain FTC
4-year O-level Secondary education. (Technical, Agriculture, commerce, etc, secondary schools.)
1-2 year NVTS to obtain GCEE or TCE
4% of primary school leavers
< 1% of prim. sch. leaver
on-job-trainee (about 2%)
Seven year compulsory Primary Education
Pre-primary Education in Nursery Schools
Legends
normal path
special case

Figure 7-1: Pyramid of Education (Technical Career) in Tanzania

Referring to the pyramid of education in Tanzania, a pupil, after completing the primary education, has options of joining ordinary level secondary schools (normal schools with a bias of business, agriculture, commerce, etc, or technical secondary school), national vocational training schools (NVTS), or end up to be an on-job-trainee. However, it is only those who can secure the very few places in the secondary schools who join them. In 1981, out of 356,905 pupils who had earlier completed their primary education, only 14,104 were selected to join secondary schools in 1982 (both in private and public schools), which represents only 3.92% of all the primary leavers of 1981 [64].

For those who are not selected to join secondary schools, about 1% can get opportunity to join the NVTS. The type of examinations found in NVTS and other trade schools are General Course in Engineering Examination (GCEE) and Technicians Certificate Examination (TCE). Graduates from NVTS and trade schools may be employed as artisans grade III. In a special situation, the best pupils in NVTS can get an opportunity to join technical college. The rest of the primary leavers, about 2% may be employed as on-job-trainees, while the vast majority of them either become peasants or end up jobless.

The Ministry of Labour and Social Welfare conducts trade tests (TT) from time to time for graduates of NVTS and on-job-trainees, thereafter, the examinees may be given certificates which show their level of skills. These tests include trade test grade III (TT III), trade test grade II (TT II), and trade test grade I (TT I). Trade test grade I are more skilled than trade test grade II and can work independently, while trade test grade II needs a little supervision. Trade test grade III is the lowest level an artisans can obtain, and with it they need regular supervision on their work.

Most of the artisans are very good in machining and other manual work, such as auto mechanic, drafting, electrician, etc., some of them can read simple engineering drawings, but may have difficulties in reading complicated engineering drawings and maintenance manuals. This group is classified as semi-skilled manpower in the technical field. Hence, out of about 400,000 Tanzanians who complete the standard seven each year, only about 3% of them can eventually become at least semi-skilled manpower in the technical field. This is to say that the scarcity of skilled personnel in technical field is a genuine problem due to a low number of technical personnel the available institutions are able to produce.

In 1981 there were only 2 technical colleges in Tanzania with a total of 1,357 learners [66]. The technical education has a duration of 3 years after which a learner graduates with a Full Technician Certificate (FTC). FTC holders, and form six graduates may continue with advanced studies in the technical college for three years to qualify for a Diploma in Engineering (Dip (Eng.)), or may join the university, after a 2 year work experience for a B.Sc (Eng.) studies. In the Tanzanian context, Dip (Eng.) is equivalent to B.Sc (Eng.).

Faculty of Engineering (FoE) of the University of Dar es Salaam (UDSM) was established in 1973 with a first in-take of 61 students [67]. Currently FoE has the capacity for 180 first year students (0.05% of the primary school leavers per year). The number include 20 agriculture engineering students who transfers to Sokoine University of Agriculture (SUA) after their second year of study at UDSM. Up to this time, there are only two universities, UDSM and SUA. SUA, which up to 1984 was just a faculty of agriculture of UDSM, offers only agriculture engineering (along with other agricultural biased degree). FoE has departments of Civil, Electrical, Mechanical, and Chemical & Process Engineering with a total intake of 160 students per year in the four departments. So, the two universities can produce a total of 180 engineers if each of the departments would produce engineers to its full capacity. This number includes 60 civil engineers, 40 mechanical engineers, 20 electrical engineers, 20 chemical engineers, 20 process engineers, and 20 agriculture engineers.

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The available government statistics show that in 1974 about 90% of civil servants in the government were Tanzanians, but they were meeting only a little over 50% of requirements in the high and middle grade manpower (i.e. those who were holding the position were semi-qualified personnel), especially of technological and scientific backgrounds [68]. It seems that this situation has not changed in almost 20 years following this survey, nor after 17 years of existence of the FoE. The questionnaire analysis showed that 40% of the industries did not have even a single engineer, hence the problem to be addressed: what is happening to all the engineers who are produced by all the institutions during this period ? Where are the engineers ?

Table 7-1 shows manpower requirements in the public sector and the expected output from local institution (the figure shown is for the degree holder manpower requirements only). The table shows that there was a shortfall of about 1,000 engineers during that period, but the engineer output from FoE almost doubled during the same period (from about 60 in 1977 to about 110 in 1984).

Given this amount of engineers from local institutions, plus at least 200 other engineers from universities abroad per year [69], (refer table 8 in ministry of national education report 1970-1975) the shortfall in the five year period should have been equal to zero. But up to now there has been a very big scarcity of engineers, although the data showing the amount of engineering jobs created during this period is not available to justify this fact. Hence, the only conclusion which can be drawn from the information available is that lots of engineers either quit the employment, or flee the country to find better working conditions in other countries.

Table 7-1: High-level manpower requirement

Field	Total Requirement in the Plan Period	Total output from the Institutions 1975/1980/1981	Difference (Increase or Shortfall)*
Medicine	793	346	- 447
Administration	2 523	1 170	-1 353
Engineering	1 481	438**	-1 043
Teaching-Arts	591	517	- 74
Science	1 140	603	- 537
Agriculture	166	240	+ 74
Law	610	372	- 238
Others	972	335	- 637
Total	8 276	4 021	-4 113

Source: Ministry of Manpower Development

* Actual manpower shortage is greater than the shortfall figures shown in the table, since some of the posts are held by less-qualified officials.

** Including Diploma holders from technical collages.

For many Tanzanians, skilled and unskilled, lack the basic needs which Maslow's [70] described as physiological needs. Hence, the best motivation they can be given at this stage is enough salary to meet their basic needs. But, the salaries of Tanzanians are too low to live on due to the current economic hardships. To make a living, a lot of Tanzanians must take on more than just one job; they may either run a poultry farm, a dairy farm, or perform extra work related to their profession. During the 1990 May day rally, President Mwinyi admitted that the salaries given are not enough to meet the people's basic needs [71].

Another possible incentive for the skilled manpower who are still working in Tanzania is to make them feel appreciated by offering them challenging tasks. This will make them utilize their knowledge at work, feel satisfaction and, at the same time gain experience. Herzberg found that long-term satisfactions in work stemmed more from achievement, opportunities, recognition, and the like; things built into work, not just added on [72].

Reward may also change the present behaviour among the skilled manpower. Skinner found that people tend to repeat behaviour that is rewarded, avoid behaviour that is punished, and drop behaviour that produces neither [73]. The reward may be financial, service, or even a study tour to an industrialized country, so that they can increase their knowledge by learning from their counterparts in other parts of the world.

In addition to physiological needs, the skilled manpower have a higher social need of being recognized, since for their training they spent more time in institutions, and therefore, those who did not spend as much time should see the difference. One way of being so recognized is to be offered a position in an organization structure in which intellectual decisions can be made without interference from the top management. For example, in the maintenance department, the engineer should be able to: make and control his/her own budget; appraise and apprehend his personnel; and in coordination with the production department prepare the maintenance program.

For the semi-skilled manpower, in addition to more salary to meet their basic needs, it is also important to increase their knowledge by giving them more education and training. Education in this context, refers to increasing mental abilities, while training refers to increasing the expertise on a specific function. Training can be offered using the available facilities within the company, during the evening after normal working hour.

7.3 Record Keeping:

Most of the maintenance departments in Tanzanian industries don't keep records of work performed on equipment when a repair or a maintenance activity is done. Of those who responded to the questionnaire, 50% did not have financial data, while a few of them claimed this was a confidential information, but, the majority of them confessed that they don't keep records. For the rest who keep records, they mainly record the total work done during a week through weekly reports, including the amount and cost of spare parts consumed during that week. It is almost impossible, with this type of information, to find a specific data for a particular piece of equipment: number of breakdowns; the causes of the breakdowns; the time taken to rectify each breakdown; amount and type of spare parts used; the amount and type of personnel required; and lost production caused by the downtime of the equipment.

Record keeping is important for the following reasons:

a) **Failure analysis:** in order to be able to determine the real cause of failure and, hence, to be able to determine the appropriate type of maintenance action to be done, then it is important to keep records for each piece of equipment.

b) **Maintenance cost analysis:** the maintenance cost is not just the cost of spare parts and labour, but it also engulfs all the costs associated with the equipment when it fails. Cost of maintenance should include labour cost, material cost (spare parts, lubricants, etc.), downtime cost (lost production due to planned and unplanned downtime caused by the equipment), opportunity cost (cost of lost customer due to unavailability of the product in time due to both downtimes), cost of spoiled material which were on the process line when the failure occurred, and overhead cost.

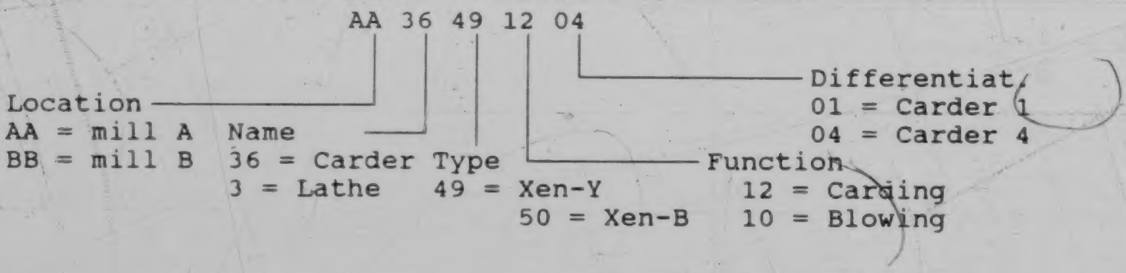
c) **Preventive maintenance planning, organization and implementation:** an effective preventive maintenance is based on the previous performance of the equipment; without specific information about each piece of equipment, it is impossible to determine its past performance, and hence, be able to prepare an effective preventive maintenance program for it.

d) **Condition based maintenance (predictive maintenance):** this type of maintenance is purely based on the maintenance information of each piece of equipment, recorded with the assistance of monitoring device. In order to be able to conduct the condition based maintenance, there must be record keeping for each piece of equipment, otherwise a random record keeping, which does not specify a particular piece of equipment, will not be useful for condition based maintenance.

e) **Quick response to breakdown maintenance:** it is said that, "history repeats itself, and those who don't learn history repeat it". Similarly, the present type of breakdown might have happened in the past, and after spending a very tedious time, the problem was identified and solved. By record keeping it is possible to avoid repeating the mistakes done in the past. Also, it is possible to just copy the right solution performed in the past for a similar problem without undergoing troubleshooting, and at the same time do the right type of maintenance right at the first time. This will help to shorten the time required to diagnose the failure, to do failure analysis, and to rectify the problem. But, without the proper documentation of the previous work done on the equipment, every time failure occurs, the maintenance crew have to start from scratch.

7.3.1 Types of Information to be Recorded:

All information useful in calculating the past performance of the equipment, such as mean time between failure (MTBF), mean time to repair (MTTR), mean waiting time (MWT), types and amount of spare parts replaced should be recorded. The first step in starting record keeping is to prepare an inventory of all equipment, which must be maintained and, which falls under the responsibility of the maintenance department. Each piece of equipment should be identified by name, type, location, and function. The identification of a piece of equipment may be by an alpha-numeric number. The information should be as concise as possible and should be distinguishable from similar equipment with the same name, location, function and of the same type. For example, suppose there are several carders in mill A of a textile mill; all of which do the same function, and are of the same type. The identification of these machines may be as shown in figure 7-2, the first two letters standing for the location, the first two numbers standing for the name, the second two numbers for the type, the third two numbers for function, and the fourth two numbers standing for a differentiation number for equipment which is more than one. All equipment in the company which needs maintenance should be included in the equipment inventory card (EIC), as shown in figure 7-2.


AA 36 49 12 04
Location
AA = mill A
BB = mill B
Name
36 = Carder
3 = Lathe
Type
49 = Xen-Y
50 = Xen-B
Function
12 = Carding
10 = Blowing
Differentiat
01 = Carder 1
04 = Carder 4

ID Number	Name	Type	Location	Function	Machine #
AA36491201	Carder	Xen-Y	Mill A	Carding	Carder 01
AA36491204	Carder	Xen-B	Mill A	Carding	Carder 04
WW23160801	Lathe	CN-M/C	Workshop	Turning	Lathe 01

Figure 7-2: Equipment Inventory Card (EIC).

Another type of a card, which will function as a summarized logbook of the equipment, is required to keep the history of the equipment. An equipment history card (EHC) identifies the equipment by its ID number only, which saves space for other historical information pertaining the equipment. EHC is very concise, which differentiate it from other work order cards such as inspection card (IC), job order card (JOC), maintenance work card (MWC), (refer chapter 8), which have detailed information.

Information available from EHC includes: a) ID number which indirectly informs about location, name, type, function and differentiation number of the equipment; b) date on which the

Equipment ID Number : AA 36 49 12 04
Equipment Serial # : Manufacturer:

Date	Task	Problem Found	Parts Replaced (Amount)	Down time	Personnel Title (Amount)	Work Number
030489	Insp.	Worn-out comb Too much Vibration	Nil	20 m	Technic. (2)	IC085678
040489	Repair	Worn-out Comb and Bearing	Bearings (4) and Comb (1)	2 h	Technic. (1) Artis.(3)	JOC08674 MWC00675

Figure 7-3: Equipment History Card.

task was performed and number of hours/revolution the machine had run without failure; c) the specific task performed; d) the problem identified; e) parts replaced; and f) downtime which encompasses the mean repair time (MRT) and mean waiting time (MWT) or just the mean downtime (MDT) (the time in which the equipment was down for repair or for inspection purposes). This is useful in the calculation of total downtime in a year, and also in cost accounting for lost production due to downtime. Time is a very important factor in maintenance cost accounting, because labour cost, lost production cost, cost of lost customer, etc, are mainly based on downtime.

The other information available from EHC include: type and amount of personnel used to perform the task; and work order number which is important for cross reference for detail information about the problem. The work order number should show whether it is an inspection card (IC), Job order card (JOC), or maintenance work card (MWC), etc., in which the detail information can be found.

7.3.2 Computer Application in Maintenance Management:

The card system is useful for both manual and computerized maintenance management and, can be applied by both small and medium size industries. But, if there is a large number of pieces of equipment to be maintained, this system may be cumbersome and tedious for manual systems. It is obvious that for each task at least two different cards must be filled, one for work request and another for detailed information of the work done. With time, there will be a lot of information on a pile of different cards, which eventually will be very difficult to retrieve. Also, with a manual system, many employees will be required to retrieve and update the information.

On the other hand, with computerized maintenance management, a single trained employee could update, and retrieve the information in a very short time. In addition, the computerized system will require uniform information to be kept and retrieved. Other sectors of economy in Tanzania are entering the computer world in a high speed (appendix 3 shows the computer situation in Tanzania), but it is doubtful whether any of the maintenance departments has started to computerize their maintenance activities.

Computer application in Tanzania is mainly limited to financial and market information. Benefits of computerized maintenance management have already been discussed in section 4.4.3.2 in this thesis. So, until efforts to keep records up-to-date are made, and the maintenance managers starts to understand the importance of computerized systems, the maintenance sector will be left behind in technological development in Tanzania.

7.4 Communication:

This section will address the communication problem between the maintenance department and other departments, and also within the maintenance department itself. More than 90% of Tanzanian industries, which employ at least 80 employees are public companies with the government owning at least 60% of the shares. Formerly, except for the new companies, all of them were under NDC which took over all the nationalized companies. Due to the fact that all these companies were under the same parent company NDC, they developed almost similar organization structures.

Tanzanian industries have the "pyramid" organization structure with very formal vertical communication only. Although there is informal horizontal communication, especially among friends, all formal requests have to follow the vertical channel purported to be for "work discipline". This communication system has the problem that top managers of departments become overloaded with a lot of information, which cause them to take a very long time to respond, and, sometimes they don't respond at all to some requests. This problem was also observed by Holmberg and Svensson, in their case study at Tanzania Portland Cement Company (TPCC), they observed that,

"... All information between divisions is given through vertical communication, it has to pass by the top management before going to the involved sections, [...] one problem is that a lot of information seems to stop at the top management level and never reach the target section ...." [74].

A breakdown, whether minor or major one, may be detected by maintenance personnel through routine inspection, or, by a mere chance of being at the site during the breakdown. But most of the time, breakdowns are detected by the production personnel. With this system (vertical communication only), the production personnel has to report the failure to his/her foreman, who in turn reports to his/her superior, and so on before the breakdown is reported to the maintenance department. Consequently, the mean waiting time is very large increasing the downtime of an equipment. If there was a horizontal communication, the foreman of the production department could directly report the problem to the maintenance foreman and, a proper action could be taken immediately.

The same bureaucracy which exists at the division level, also exists at the department and section levels. Matrix organization structure would be an ideal structure for a Tanzanian industry which experiences frequent machinery breakdowns. This will minimize the downtime, which hitherto is not accounted for as a maintenance cost by many Tanzanian industries. However, the matrix structure should be introduced carefully because sometimes may cause conflicts, especially.when a subordinate receives two orders from two different bosses.

7.5 Lubricants and Lubrication Programs:

An unavailability of manufacturers' recommended lubricants in Tanzania is a common problem. This problem affects the quality of lubrication applied to an equipment. Most of the lubricants are identified by the maintenance personnel by their trade names such as Esso-HD, Esso-LD, etc.. The majority of the maintenance personnel have a very low level of education, hence to them oil is oil, what matters most is the trade name. Sometimes the maintenance personnel use oil of different viscosity to the recommended one, given that it has the same trade name.

In addition, the unavailability of planned programs for machinery lubrications adversely affects the life of machine components which must be lubricated. Lubrication is done impromptu when the foreman feels like doing it, or when the machine parts starts to squeak due to lubricant starvation.

Lubrication of any machine part is important as lubricants have the several benefits to the machinery, or moving machine parts. Lubrication oil provides: a) a hydrodynamic film between relatively moving metal parts which prevents metal to metal contact, and hence, preventing wear and scuffing of the parts; b) oiliness effect which prevents rusting of ferrous metal parts, and corrosion especially in copper-lead bearings; and c) a cooling effect for internal parts of the engine, such as piston, cylinder, and crank shaft.

All lubricants do not have the same properties, for example, virgin lubricants have poor viscosity, they form foam, and enhance oxidation. Hence, some additives have to be added to the oil to improve its physical and chemical properties. The additives which are added to the virgin oil include viscosity index improvers, oiliness agents, wear reducers, antioxidants, detergent-dispersants, antifoam agents, extreme pressure agents, seal swellers, and friction reducers [75]. These additives add extra properties and functions of lubrication oil such as prevention of sludge formation, and reduction of engine friction which improves fuel economy [76].

Three American institutions American Petroleum Institute (API), American Society for Testing Materials (ASTM), and Society of Automotive Engineers (SAE), are playing a big role in standardization of oils and oil measurements. Lubrication oils are identified by a SAE number which is based on viscosity (defined as a resistance to flow of the oil) of the oil. Normal lubricants are identified as SAE 20, SAE 30, SAE 50, etc., while winter oils are identified with "W" added to the SAE number such as SAE 10W, SAE 20W, SAE 30W, etc., (note that SAE 10W is different in chemical and physical properties from SAE 10). SAE classification of engine oils is shown in table 7-4 [77], the higher the SAE number the higher the viscosity of the oil.

Table 7-2 SAE Viscosity grades for Engine Oils

SAE Viscosity Grade	Viscosity (cP) at temperature (°C) Max	Borderline Pumping Temperature °C Max	Min	Viscosity (cSt) at 100 °C. Max
0 W	3250 at -30	-35	3.8	---
5 W	3500 at -25	-30	3.8	---
10 W	3500 at -20	-25	4.1	---
15 W	3500 at -15	-20	5.6	---
20 W	4500 at -10	-15	5.6	---
25 W	6000 at - 5	-10	9.3	---
20	---	---	5.6	less than 9.3
30	---	---	9.3	less than 12.5
40	---	---	2.5	less than 16.3
50	---	---	6.3	less than 21.9

Absolute viscosity is measured in "Poise (P)", but the commonly used unit is the "centipoise (cP)" which is the hundredth part of the poise. In laboratories it is easier to measure kinematic viscosity (using "Stokes (St)") than absolute viscosity. But, the "centistokes (cSt), which is the hundredth part of the stokes is commonly used. Relationship between the absolute viscosity (in cP) and kinematic viscosity (in cSt) is given by:

$$\boxed{\frac{cP}{\text{Density}} = cSt} \tag{7.1}$$

Another important parameter which is normally included in the lubrication oil is the "Borderline Pumping Temperature (BPT)", which is defined as the lowest temperature at which engine oil can be supplied in adequate amount to the oil pump inlet [78]. This BPT, is very important especially in a very cold weather application, in which a wrong selection of the type of lubricating oil to be applied can lead to malfunction of an engine. The higher viscosity oils provide a larger hydrodynamic film even at higher operating temperatures, but unfortunately, these oils are too thick for efficient pumping at low temperatures. However, low temperature is not a problem in Tanzania, the lowest ever recorded temperature is 2°C. in elevated area of Mbeya [79].

Relationship between temperature and viscosity is measured by the so called viscosity index (VI) scale. In this scale, the lubrication oil which has the **least change** in viscosity with a change in temperature, has the highest VI. The use of viscosity index improvers helps to balance the viscosity of lubrication oils at different operating temperatures.

Lubrication oil is consumable as is fuel, the only difference is that lubrication oils have slower rates of consumption than fuels. Oils of higher VI are consumed at slower rates than oils with lower VI. Also, it has been established that the engine operating conditions, such as speed, loads, and environment conditions, affect the rate of consumption of the lubrication oils [80]. Hence, it is advised to monitor frequently the level of lubrication oil, especially in hot climate, as the rate of consumption of lubrication oil is affected by climatic condition.

A very high level of lubricants is as bad as a low level of lubricants. The higher levels of lubricants increase internal fluid friction in the engine and reduce the efficiency of the engine, while the lower levels starve other parts. In addition, lubrication oils are contaminated by metal debris when wear takes place. So, it is important to ensure that there is a well planned program to lubricate machines to the recommended levels at regular intervals. This will ensure that the lubrication oil is at the recommended level, and that it is also clean.

7.5.1 Lubricants Recycling:

Recycling of used lubricants can be a very big source of lubricants. This potential source of lubricants is often ignored in many countries, consequently, used lubricants is treated as a waste to be disposed. In western Canada, a statistical survey in 1974 showed that, out of 30 million gallons of new lubrication oil sold, only 6 to 7 million gallons were re-refined [81]. In USA, according to the department of energy (DOE), in 1977 over one billion gallons of used oil were generated (equivalent to 70,000 barrels a day), and only one-half of this amount was recovered [82].

In Tanzania, there is no information available explaining the amount of used lubricants generated each year, and whether there is any recycling or not. Scenes of "road side" used as dumping places of used oils are very common in the city and towns. Although the situation is not yet alarming due to the small number of motor vehicles and industries available, this practise should be discouraged. Even before having a lubricant recycling plant, which could utilize all of the used oil, proper methods of disposing the used lubrication oil should be encouraged for environment sake. Recycling of used lubricant in Tanzania would be of both environment and economic benefit.

The main hesitation among the users of lubricants to use the recycled lubricants, is due to uncertainty of its physical and chemical properties. The tests which have been conducted show that re-refined oils exceed the minimum requirement for lubricants under military specification MIL-L-46152 [83]. A recycled lubricant is like a straight mineral oil without any additive, hence, the re-refined oil may be used for other purposes. If the re-recycled oil is blended with other additives such as VI improvers, and antioxidants, it can be used for its original intended use as any other new lubricants.

The hydrazine-treated used lubricants were reported to have improved oxidation and colour stability, and after addition of oxidation inhibitors and sludge dispersants, produced an oil equal to or better than virgin oil [84]. So it can be concluded that there is no sacrifice either on physical or chemical properties of lubricants when recycled.

7.5.2 Lubrication Program:

This section deals with question of who is responsible for machine lubrications, and how lubrication activities can be performed without affecting other maintenance, or production activities. It only a very few pieces of equipment can lubrication be done safely without shutdown of the equipment. Hence, coordination of lubrication with other maintenance and production activities is very important. Also, the purpose of establishing a lubrication program is to ensure that, equipment is lubricated at the proper time, using a proper lubricant (having the recommended ingredients), and at a right amount (not too little and not too much).

The first step in establishing a lubrication program is to make a survey of equipment in order to: a) establish the required types and amounts of lubricants; b) to mark the lubricating point; and c) to establish lubrication cycle for each piece of equipment in the company. The survey should not be limited to external visible points only, but should also be accompanied by engineering drawing reading to expose hidden points which need lubrication. The survey will be useful in establishing lubrication activities which must be done while the equipment is shutdown, and those which may be done while the equipment is running. The same equipment ID number used in section 7.3.1 may be used to make the survey, and to record the type of lubrication required for each piece of equipment.

The second step is to summarize the survey findings, and hence, to establish lubricant requirements within the company in a standard form. Unless it is strictly required to use a certain standard of lubricant, say SAE 15 for precision equipment, the other lubricants may be categorized as light duty (LD - SAE 10 to SAE 30), medium duty (MD - SAE 30 to SAE

50), and heavy duty lubrication oils (HD - above SAE 50). Additional categories may be set according to the precision requirements, the standard to be established, and availability of the lubricants.

The third step is to paint the lubrication points (nipples), lubricant containers, and lubricant guns according to the three or more "duties" established, such as white for light duty, blue for medium duty, and black for heavy duty lubricants. This visual aid will help the less educated maintenance personnel, to distinguish different lubricants, and hence, to avoid mistakes of using wrong ones. This process will also reduce contamination of lubricants, caused by using the same gun to lubricate different equipment, which use different lubricants.

The fourth task is to establish a lubrication schedule according to a lubrication cycle required for each piece of equipment. As discussed, in a very hot weather, lubricants are consumed at higher rates, hence a frequent inspection on the oil level should be encouraged in hot weather areas. The lubrication schedule must take into consideration of activities which will require a shutdown of the equipment. With good coordination activities, which needs a shutdown, may be performed during normal shutdown for other maintenance activities.

The fifth and the last task in establishing lubrication program is to allocate manpower to do the lubrication. Lubrication may be performed by a technician, or by a trained artisan. A basic training in types of lubrication, amount of lubricant required, how to read oil level, and methods of injecting lubricants in a proper way, may be introduced to all foremen, technicians, artisan and machine operators.

Lubrication is a preventive activity, and as with any other preventive activity, it is a responsibility of preventive maintenance personnel to ensure that lubrication program is implemented as planned. However, Brig. Apte [85] proposes that preventive maintenance and lubrication should be separated to avoid borrowing people from preventive maintenance to meet a lubrication load. But, if lubrication would be given the same priority as any other preventive maintenance activity, then the problem of borrowing preventive maintenance personnel to do lubrication would not occur.

7.6 Maintenance Organizations and Implementation:

This section deals with the organizational position of maintenance department, and, its effect in implementation of the maintenance programs. The section also discusses the organization of maintenance activities within the maintenance department itself.

A typical organization structure of a Tanzanian industry, which is almost the same as the one proposed by an American consultancy firm Messrs. Mckinsey and Co. to NDC in 1968 [86], is shown on figure 7-4. As discussed, most of the industries in Tanzania have almost the same organization structure due to their history of being under the same holding company NDC. In this organization structure, plant maintenance is placed under production division or in other industries known as operation

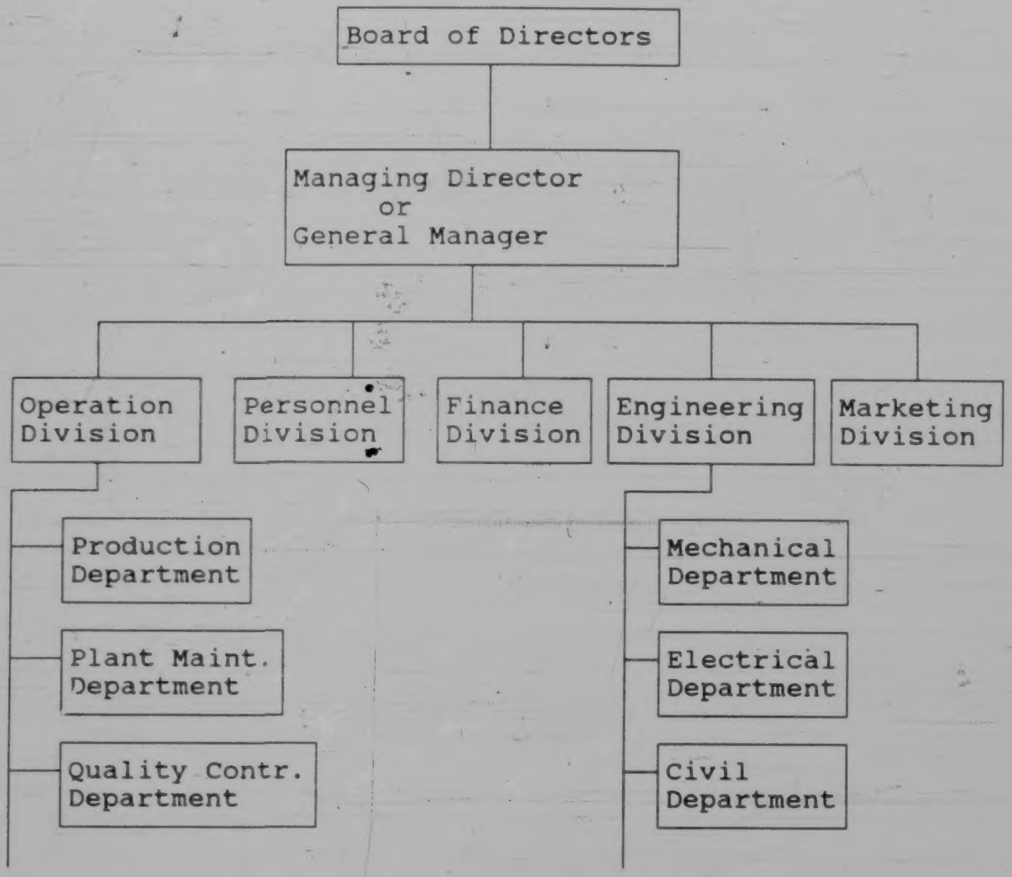

Board of Directors
Managing Director or General Manager
Operation Division
Personnel Division
Finance Division
Engineering Division
Marketing Division
Production Department
Plant Maint. Department
Quality Contr. Department
Mechanical Department
Electrical Department
Civil Department

Figure 7-4: A Typical Organization Structure

division (appendix 4). The main problem with this structure is that the head of the division become more interested in production than plant maintenance, consequently plant maintenance is given a very low priority.

For example, suppose there is a planned shutdown for preventive maintenance, at the same time there is a production order from a certain customer which is in the pipeline. In such situation, the shutdown will be postponed to meet the order of the customer. The shutdown won't even be implemented until there is a major breakdown in which the maintenance department will be rushed to restore the broken plant. On the other hand, if the maintenance department was under another division, which has the same authority as the operation division, it would not be so easy to postpone maintenance programs as is presently the case.

Although the maintenance department should be as close to the production department as possible (refer to section 4.2), with the Tanzanian situation, in which the maintenance culture is not yet developed, maintenance programs will be adversely affected. Hence, in a situation like Tanzanian, it is strongly recommended that, production and maintenance departments be under different umbrellas, otherwise maintenance will always suffer.

A typical maintenance department of a Tanzanian industry is shown in figure 7-5. It is a maintenance department of TPCC, and the number in the parenthesis represents the number of employees in each section. The maintenance department is one of the four departments under the operations division, the other being the production, materials, and quality control [89]. The maintenance department is divided into 6 sections: preventive maintenance; garage for motor vehicle and forklifts maintenance; plant maintenance; workshop; electrical engineering; and civil engineering section.

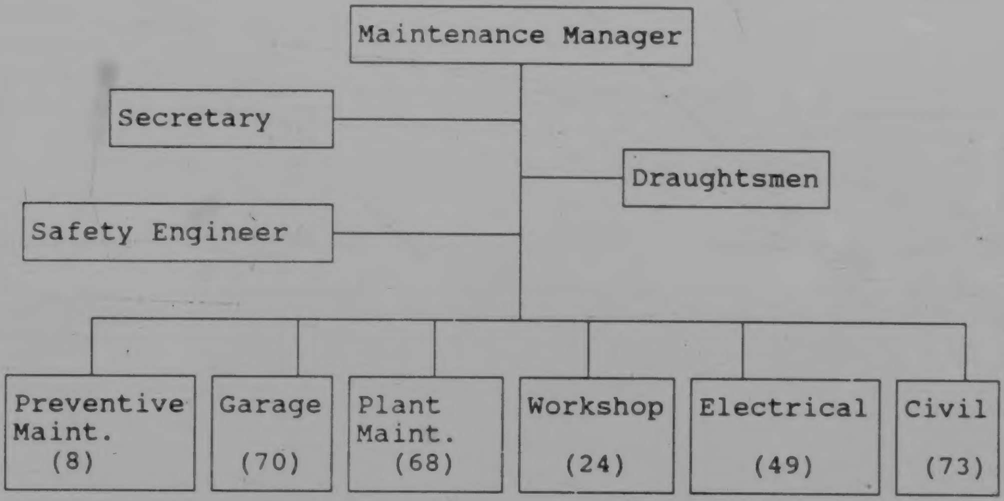

Maintenance Manager
Secretary
Draughtsmen
Safety Engineer
Preventive Maint. (8)
Garage (70)
Plant Maint. (68)
Workshop (24)
Electrical (49)
Civil (73)

Figure 7-5 TPCC Maintenance Department Organization Structure

The interesting point to note in this department is the size of preventive maintenance section, which is the smallest in size, with only 8 employees. The concept of preventive maintenance in this company is limited to cleaning, lubrication and condition monitoring [90]. Since the department does not have the modern equipment for condition monitoring, the main task of preventive maintenance section is lubrication and preparation of preventive maintenance cards (PM-cards). It is obvious that in this department, preventive maintenance is of less importance than the other types of maintenances. Other sections which do mainly corrective maintenance are given more employees, which imply that they are given higher priorities than preventive maintenance. The main problem is misconception of the role of preventive maintenance. If the role of preventive maintenance in this company would be expanded to include inspections and services (refer section 6.3.3.2), then it would be given more attention.

In organization of maintenance activities, one of the major problem is to understand the role to be played by the maintenance department. In many Tanzanian industries, the responsibility of maintenance departments is to keep the plant and equipment in a good condition. But, what is done by majority of them is arresting the breakdowns; very little effort is done to prevent the breakdowns which is the role of preventive maintenance. That is why the sections in maintenance departments which are responsible for repair are given more employees than those which are concerned with preventive maintenance. If preventive maintenance would be performed to its full capacity, then the role of breakdown maintenance could be drastically reduced. Unfortunately, this is a truth not yet known to the majority of maintenance personnel in Tanzanian industries. To them, plant maintenance refers to lubrication and repair when the plant breaks. So, it is important to define clearly the function and responsibilities of a maintenance department.

Another organizational problem which hinders implementation of maintenance programs is the rigid vertical structure. The organization structure should be flexible enough to allow lateral communication and flow of work orders. In many situations the inspection task or repair work needs both mechanical and electrical personnel at the same time. If there is no proper coordination between these two sections, then it will be difficult to perform the job in the proper way. In addition to the fact that introduction of preventive maintenance in many industries is met with reluctance from the maintenance personnel, who are used to their old ways of doing maintenance work, the present organization structure plays part in difficulties of implementation of preventive maintenance programs. For example, at TPCC the preventive maintenance section introduced PM-cards and check lists to be used in plant maintenance section but no one in plant maintenance section took them seriously [91]. Consequently the whole preventive maintenance program is in a moribund stage. On the other hand, if the maintenance department could centralize its activities, or change the present organization structure to a matrix like structure, the present implementation problems could be highly reduced.

7.7 Summary:

An in-depth analysis of the maintenance problems in Tanzania has revealed that the main problem are within the organization structure of the companies and the management of the maintenance activities. The present organization structures cause difficulties in initiating and implementing maintenance programs. The maintenance department is in inferior position relative to its importance, or, is just a section of production department. In that situation, the maintenance programs are given lower priority to production programs.

Although it is true that there is also a spare parts problem, but, this is a result of mismanagement. If there was an effective record keeping system, and, an effective preventive maintenance program, then it could be possible to plan for spare parts acquisition. In addition, the spare parts problem is exacerbated by the industrialists themselves depending too much on imported spare parts. If efforts could be made to produce the spare parts locally, then this problem could be highly reduced.

Unavailability of skilled manpower may be classified as a genuine problem due to the low output of skilled manpower from the institutions available. Only 0.05% (ie 5 out of 10,000) of those who complete primary education can get a chance to study engineering at the university level. There is no data available to show how many engineers have be trained so far, and the number of engineering jobs which have been created, but it is an open secret that, lots of highly trained manpower are leaving the country due to poor working conditions. If efforts could be made to retain these trained manpower at home, this problem could also be eliminated in a very short period.

Other problems including: lubrication programs; record keeping; and information systems; could be solved at the company level by putting very little effort. It is high time now to start computerization of maintenance records and maintenance information systems. This will help in re-organization, failure analysis, and implementation of maintenance programs. While other sectors of economy in the country are entering the computer world at a very high speed, the maintenance sector will be left behind if no proper effort is made to keep records, and to train personnel to use computer.

8.0 A Maintenance Model for a Tanzanian Industry:

8.1 Introduction:

This model is intended for a mediocre Tanzanian industry, of medium size, having the common problems of spare parts, skilled manpower, working tools, etc.; but, the model may also be applied by small and large size industries. The model is based on various information from previous chapters, which described maintenance problems in Tanzanian industries. From the questionnaire analysis, it is obvious that at least 50% of the industries did not have a planned preventive maintenance program: about 50% indicated that they did not keep maintenance records; 20% had high failures per week; 45% average failures per week; and, 35% low failures per week (refer table 3-1 & 3-3 in chapter 3). In table 3-7 (chapter 3), the replies shows that 90% practised breakdown maintenance to almost every equipment, 40% unplanned preventive maintenance, and 50% showed preventive maintenance in some equipment.

In chapter 6, various maintenance systems were analyzed. The analysis showed that breakdown maintenance is economical applicable only on trivial and unimportant equipment, hence, it is inappropriate to apply breakdown maintenance to every piece of equipment. In Tanzanian situation, it is even worse to apply breakdown maintenance due to difficulties in spare parts procurement.

In viewing the maintenance problems and the economical maintenance system, this model is developed to introduce a planned preventive maintenance for every piece of equipment in the company. An effective preventive maintenance program will reduce failures and hence, eliminate the breakdown maintenance system. The term preventive maintenance in this model will refer to both regular and condition based preventive maintenance.

In a detailed analysis of the maintenance problems in Tanzania, it was evident that the major problems were, the organization structures of the companies and, management of the maintenance activities. With the present organization structures it is difficult to implement the maintenance programs. Maintenance activities are given low priority due to the inferior position of the maintenance department in the organization structure. Consequently, the maintenance activities are not given high priority in the budget and other financial matters. Hence, in order to implement this project effectively, it is necessary to reorganize the present structure of the whole company, involving a reorganization of the divisions and departments. The reasons for the reorganization are: a) to create flexibility within the present organization; b) to increase efficiency of work performance; c) to reduce the work load of the top managers by giving their subordinates more responsibilities; and, d) to reduce bureaucracy in decision making.

The model requires the creation of a new technical division within the present organization structure. The following departments are recommended to be under the technical division: maintenance; all engineering departments (mechanical, electrical, civil, chemical, etc); and, all technical support departments (boiler, machine tools workshop, refrigeration, foundry, etc).

The intent of creating this new division is not only to separate maintenance and production departments, but also to increase the efficiency of executing maintenance programs in Tanzanian industries. In chapter 4, it was shown that maintenance suffers whenever maintenance and production departments are under the same umbrella. Hence, the model intends to separate the two departments without affecting their performances and interdependence. The new technical division should be created totally from reorganization of the present organization structure. This imply that the new division should be created without employing new workers, or, purchasing new equipment. But this does not mean to block the company from acquiring new resources even if it is absolutely necessary. What it mean is, before acquiring any new resources (skilled manpower, machine tools, etc.), the company should make sure that the existing resources are fully utilized.

After solving the structural problem, the next task is to solve the management problem. It is strongly recommended that the manager of the technical division should be an engineer. Selecting a technical personnel to head the technical division will ease communications within the division: the manager will be more conversant with the technical vocabulary; and, will be more familiar with the technical problems than a non-technical manager. The present manager of the engineering division (figure 7-4), may be appointed to be the manager of the new technical division. The heads of departments may remain the same, even with the head of plant maintenance department, but engineers would be the preferable choice to head the departments.

It is recommended that the official communication within the divisions and departments should be both vertical and horizontal. Only the critical communication, which needs the decision of the top management, should be communicated vertically. This imply that the foremen should be given more decision making powers. Presently, almost all decisions are made by the managers of the divisions (refer to section 7.4) or heads of the departments.

8.2 System Design:

8.2.1 Function:

The problems which should be tackled simultaneously by both the maintenance department and the company as a whole are: the scarcity of skilled manpower and spare parts; frequent equipment breakdowns; and, low capacity utilization. The main purposes of the system design are: to make full utilization of the few available resource (skilled manpower, spare parts, equipment, buildings, etc.); to achieve higher productivity; and, to reduce the overall operational cost.

To be able to respond to the problems mentioned, the company should start to implement a project-oriented structure. The project-oriented structure enables the company to do things which are almost impossible to do with the normal functional organization structure. Davis and Lawrence [92] suggest that, companies should turn to project-oriented structures when:

i. it is absolutely essential that they be highly responsive to two sectors simultaneously, such as markets and technology;

ii. they face uncertainties that generate very high information processing requirements; and,

iii. they must deal with strong constraints on financial and/or human resource.

The above conditions for turning to the project-oriented structure are clearly visible in the majority of Tanzanian industries. Hence, the operation of the new technical division should be a project-oriented at the early stage. At the later stage, the technical division may return to the normal functional operation as the other divisions. The main function of the technical division is to offer all necessary technical support to the operation division (such as maintenance, redesign of the equipment, retrofitting, new equipment installations, etc.). However, the technical support should not only be to production department alone, but also to other departments which will need such support such as transportation, safety, and buildings.

In addition, a new task in this new division will be to reorganize and support the maintenance department. The maintenance department should be starting to introduce real preventive maintenance for each piece of equipment, at the same time the department will have to respond to breakdown maintenance activities. A matrix form of operation (which is a project-oriented structure), is strongly recommended at this stage. The structure will enable the technical division to respond to fluctuations of manpower demands from the maintenance department when a major breakdown occurs. The division should be able to draw low level skilled personnel from any department under its authority when necessary. For example, the technical division should be able to draw manpower from workshop, foundry, boiler, etc., to assist in a major plant breakdown maintenance.

The function of the maintenance department at this initial stage are: preventive maintenance with an introduction of condition based maintenance; and breakdown maintenance; but, emphasis will be on preventive maintenance. Preventive maintenance activities may be treated as project activities, while the breakdown maintenance activities may be treated as functional activities. Hence, the same maintenance personnel may be utilized in both preventive and breakdown maintenance.

For a long range planning of the maintenance department, the main function will be preventive maintenance only. All manpower available for the maintenance department will be assigned preventive maintenance tasks only. This will be possible as breakdowns diminish with improvement in preventive activities. Any breakdown at the later stage may be dealt as an emergence situation activity.

8.2.2 Manpower Requirement:

As mentioned, it is recommended that the head of the technical division be an engineer, preferably with a rank of a chief engineer. The heads of the departments within the technical division should also be engineers whenever possible. In a situation where there are not enough engineers, a chief technician may be appointed as an acting head of a department. For the maintenance department at this stage, it is strongly suggested that the head should be an engineer, this at least will ensure that modernization of the maintenance department takes place. If there is not any engineer available to head the maintenance department, an external consultant may be hired to supervise the modernization of the maintenance department. Also, if hiring of the external consultant is very expensive, the chief engineer (head of the division) may supervise the modernization of the maintenance department.

The head of the maintenance department at this stage may wear two hats, one as a project manager for preventive maintenance project, and the other as a functional manager. However, if there are enough engineers, the two hats may be separated. The project manager must have the same status as the functional managers. It is also possible to assign another head of a different department (e.g. the head of electrical department) as the project manager.

The project manager should be relieved of some of the functional activities to give him/her spare time to concentrate on project activities. Also, the project manager should be able to recruit personnel (technicians and artisans) from different departments. The project should be given higher priority in recruiting its staff than the normal breakdown maintenance.

Foremen of the sections should be experienced FTC holders with some years of experience in manual technical work and at least low level supervision of technical job. An introductory management courses, especially in labour and project management, are recommended for all technicians and, should be compulsory for all those appointed to the foremen positions in the project. A senior artisan who have upgraded himself and preferably passed a TT I, may be appointed as an acting foreman for the functional activities. However, the artisan must be given at least a two day seminar on labour management by the department engineer to enable the artisan to lead his peers (artisans).

Trained artisans should be the lowest level of the technical personnel both on the project and on the functional activities. The present ad-hoc method of training at the work-place should be structured to include a well documented training program. Presently, the on-job-trainees learn by following the experienced technical personnel (learn by doing). The drawbacks of this program is that the trainees learn only the manual work and not background theory which limits the knowledge of the trainee. Personnel with only on-job-training (unstructured training) face difficulties in dealing with new problems. Companies are advised to either hire artisans who have completed their studies at trade schools, or prepare structured on-job-training. Also, on-job-training of the artisans after graduating from a trade school should be enhanced to make the artisan adapt to the real work environment. The training should be aimed at making the artisan more expert not only in manual technical work, but also in analytical task. The training may be in a form of either company orientation, regular seminar within the company premises, or attachment to an experienced personnel.

8.2.3 Environment:

Environment in this section of the model refers to physical, social, economical, and political factors in which the model will operate. Some of the suggestions which are relevant, and applicable in developed countries, may fail in Tanzania due to the environmental factors discussed here. For example in Tanzania, it was almost impossible to offer financial incentives to personnel due to governmental regulations. In addition, almost all companies, which are the biggest employers, are owned by the government. Hence, it is difficult for an individual company to change its organization without a go-ahead from, either the parent ministry, or, one of the big holding government companies NDC, TLAI, TEXCO, TSC, etc.

The Tanzanian environment is characterized by the following factors, which must be considered in designing a maintenance system for a Tanzanian industry: a) scarcity of physical resources such as skilled manpower, spare parts, working tools; b) low moral support from both the top management and production personnel for maintenance programs; c) low level of technology; d) total dependence on imported technology; e) a developing economy; f) low morale among the skilled personnel; g) industries which are operating at less than 40% of their capacity, hence production is a very high priority; h) About 90% of the industries are owned by the government; i) labour laws; j) very low work discipline; k) government intervention in company policies; and, l) nepotism in work-place.

Most of the above factors have already been discussed in chapter 7. Although it is recommended to avoid punitive measures in project management [93], the Tanzanian situation calls for strict work regulations and supervision in order to enforce work discipline. In fact, it is necessary to replace some of the employees, overhaul the whole system from the top to the bottom, in order to be able to introduce changes.

A social factor worth to look at is "age". In many African societies, elders are more respected than young people. It is unfortunate that some aged people, especially those who have been working with the company for a number of years, want to be given a special status. A newly recruited young engineer may face hard time dealing with the elderly people. Hence, as a project manager, it is worth to understand this socio-culture factor, and if possible avoid to recruit an elderly person in your project team.

Another issue worth discussing is the economic factor, the country is facing economic hardships. These hardships are affecting almost every individual in Tanzanian society. The salary paid, even the so-called super scale salary, is not enough. To make the ends meet, a Tanzanian worker has to do at least two jobs. This affects the performance of the normal work; there is a very high rate of absenteeism. Many workers leave the work-place either before the hour to catch the other job, or leave during the working hours to do their private work and return to their normal work. It is really disgusting, especially for somebody who does not understand the reasons for the absenteeism. So, as a project manager, it is better to give some floating time in the program to compensate for the absentees.

Technological environment is the last but not the least to be discussed in this section. Somehow this factor is ignored by many researchers, but, it hampers the development and innovation of the indigenous technologists. El-Namaki [94] noted that, whenever a Tanzanian enterprise is about to expand a plant, install a new manufacturing facility, or modernize the existing equipment or process, there is no where else to go but abroad. In that situation, the Tanzanian technologists encounter great resistances from the policy makers in the company. Hence, the idea of introducing a project-oriented structure, will no doubt face a strong obstinacy from management. Even if the managers buy the idea, the next step will be to seek an external firm to implement the idea. The best step to take is to lobby the board of directors, to authorize the managers, to give a chance to the local engineers to implement the idea before searching for an external solution.

8.2.4 The Process:

The process explains the steps to be followed in starting the preventive maintenance project in Tanzanian situation. Although there are some slight differences from one company to another, Tanzanian industries are more similar than different in culture, operation, and ownership. Any big change within the present system must start from the top. Hence, it better to know the big players at the top and, somehow manoeuvre the idea in a way that it looks like originating from the top. The first place to initialize the idea of starting the project is through the members of the board of directors (BoD). As an innovative engineer, it is possible to discuss the ideas with one influential member in the BoD.

The BoD is the highest policy making organ at the company level and is the second most important decision making crgan (after the central committee of the holding company), in a state owned enterprise. In Tanzania, except for the general manager, members of the BoD are non-executives. Members of the BoD are drawn from different institutions, such as the university, the ruling party, and other civil institutions. The BoD has the ordinary mandate of: hiring and firing of senior executives; sanctioning of expense budgets (including the capital expenditure one); approving both long and short term plans; controlling performance; measuring the adherence to set policies and strategies; and finally declaring dividends, which, in this specific case, largely go to the state [95]. Hence, if it is possible to influence the BoD, even through only one member, the idea will be evaluated much quicker than if the idea starts from the bottom.

There are three ideas to be presented at the BoD, the first being the idea of creation of the technical division which will deal with the technical activities only. UFI has a technical division, but, the production department is included in this division (appendix 2). The second proposal is to create a matrix organization structure for the technical division. The third suggestion, which is the main reason behind all this reorganization, is a proposal to start the project for implementation of preventive maintenance for all equipment in the company.

The following steps assume that all the three ideas have been accepted by the BoD. The new organization structure of the company is created, and is shown on figure 8-3 in section 8.3. The organization structure of the new technical division is shown on figure 8-4. The technical division is now fully responsible for implementation of the last idea which is finally baptised and renamed "Preventive Maintenance Project (PMP)". The division manager is the former chief engineer who was the manager of the engineering division, and he has selected a project manager who is also an engineer. The project manager is requested to: a) formalize the project; b) define responsibilities; c) explain how the project will be executed; d) illustrate what will be the expected result; and, e) justify the project completion time.

The first step in implementing any project is to create a project charter, which is a preliminary plan explaining the management of the project. Among the best template for a project charter is found in Silverman's book, **The Art of Managing Technical Projects** page 53 [96]. The charter consists of seven elements:

a) project description;

b) project priority;

c) project standards;

d) the change procedures;

e) personnel and physical resources required for the project;

f) the project cost or price and how measured; and,

g) the project administration procedures.

The project manager is responsible for preparation of the charter in the so-called top-down iteration. The second step in preparation of the charter is the so-called bottom-up iteration, in which the project team review the charter, and attach their justification. The final step is endorsement of the project charter by the top management. However, the template suggested by Silverman is modified in this thesis to avoid repetitions while serving the purposes of this research. For example, because manpower requirement is already discussed in section 8.2.2, it is only mentioned in the project description instead of creating a new chapter. In addition, the project description section is discussed in more detail to include the implementation process.

8.2.4.1 Preventive Maintenance Project Charter:

a) **Project Description:** The project aims at creating a preventive maintenance program for every piece of equipment in the company. The project is divided into four phases: phase one- fact finding; phase two- in-depth analysis of the facts found in phase one; phase three- planning for implementation strategies; and phase four- practical implementation of the strategies.

Phase 1:

In the first phase the main task is to establish a list of all pieces of equipment which require regular preventive maintenance. This includes identification of each piece of equipment by an identification number (ID), recording the ID number, and collecting the manufacturer's maintenance manual. The project engineer may start creating a computer data base for the equipment list using the Equipment Inventory Card (EIC) (figure 7-2). The first phase activities will be done by one engineer (the project manager), assisted by four technicians and eight casual personnel for sign-writing. It is estimated that three months are enough to complete the list for a medium size company with at most 15,000 pieces of equipment to be maintained.

Phase 2:

If there is ample enough skilled manpower for the project, the second phase tasks may be done in parallel with the first phase activities. The main task in the second phase of the project is to establish the required preventive maintenance program for each piece of equipment. This task includes the establishing of inspections, services, and the frequencies required for each activity for each piece of equipment.

Information from the manufacturers' maintenance manuals, company's failure reports, and consultation with experienced technical manpower, is useful in planning for inspection or service for each piece of equipment. The task requires one engineer and four technicians, for a period of two months, for the same number of pieces of equipment as in phase one. The card shown in figure 8-1 may be used in carrying out the phase two task.

EQPMT ID #	Inspections	Frequency	Services	Frequency
AA36491204	1.Comb 2.Bearing . . .	6 months 8 months . . .	Lubrication alignment . . .	2 months 12 months . . .
AA21326501				

Figure 8-1 Preventive Maintenance Project Card #1

The card shown in figure 8-1 may also be used in preparing a computer data base for maintenance inspections and services. The card is a summary of manufacturers' maintenance manuals and company's service bulletins. The card is meant for phase two activities only, it may be destroyed after completing documentation of phase three activities.

Another task to be performed in phase two is the analysis of improvement return if preventive maintenance is implemented. Any piece of equipment which does not show any prospect of improving its performance, even after introducing preventive maintenance program for it, should be left out.

nking of equipment according to either its importance on production, or, the consequence of its failure (to itself, other equipment, production, safety, etc.), is another activity to be done at phase two. If possible, for each piece of equipment the most important part, which need special attention, should also be ranked so that preventive maintenance action starts with those parts. Preventive action should start with an equipment having the highest rank in the list. Other factors which may be considered in priority ranking for preventive maintenance are [97]:

a) A piece of equipment which causes bottle neck in manufacturing;

b) A piece of equipment which exerts very big influence on manufacturing;

c) An easily breakable piece of equipment;

d) A piece of equipment which exerts great influence on the quality of products; and,

f) Equipment into which expensive raw material is charged.

Phase 3:

In phase three the main task is to coordinate the activities described in phase two, which includes the scheduling of all activities to be done for the whole project time. The whole schedule may be broken down into monthly, weekly, and daily activities. Estimation of time and manpower required to complete each activity should also be part of the third phase task. A preventive maintenance calendar card (figure 8-2), may be used to show activity to be done in one month. The card shows activities to be done on each day and the type of activity (inspection, service, overhaul, etc.). The activities in this phase may need an engineer, two technicians, and a draught man for two months.

The calendar card is useful in distributing evenly the work load for each day. Sundays and public holidays are shaded off to avoid errors of assigning activities on a non-work day. The drawbacks of this card are: a) as a planning tool, it does not show manpower and tools required to perform each activity; and, b) it is very difficult to update this card in a case of backlog, especially with non-computerized maintenance systems.

Maintenance Calendar for: January 1990															
EQPMT ID #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
AA46861301	/	O					/							/	
AA46861302	/			O			/							/	
AA46861303	/					O	/							/	
BB12324401	/	I					/							/	
BB12324402	/		I				/							/	
BB10203001	/			I			/							/	
CC15251001	/	S					/							/	
CC15251002	/		S				/							/	
CC15251003	/			S			/							/	
														/	

Legend:
I = Inspection
S = Service
O = Overhaul

Figure 8-2: Preventive Maintenance Calendar Card

Manpower requirements, time estimates, and other resources required can be determined using network analysis techniques. The well known network analysis techniques are CPM and PERT. The drawbacks of these network techniques are: a) they can't show activities which are in progress; and, b) it is very difficult and time consuming to update the networks for a non-computerized maintenance system. Other forecasting techniques which can be used are bar chart and line of balance. It is important to note that each technique has its own advantages and disadvantages, hence, the project manager has to select a technique which is more convenient for her.

Phase 4:

Phases 1-3 may be considered as planning phases, while phase 4 is an implementation of the plans. For a minimal disruption of regular plant maintenance activities, the implementation of the project should be gradual. The increase of manpower to the project should be in proportion to the diminish of breakdown activities, i.e., the manpower for the project, should be gradually transferred from the plant maintenance department.

It is assumed that there is no previous preventive maintenance program before the project was initiated. Hence, the first step is to overhaul each piece of equipment. This action will revitalize the equipment and reduce the number of breakdowns. To start, the project team consisting of one engineer (project manager), one technician (assistant project manager), and four artisans, may overhaul the first machine which is at the top of the priority list. This activity may take two to three days depending on the size and/or complexity of the machine. In one month, at least 8 machines will be revived, and at the end of the second month this number may double to 16 machines.

At this juncture, the rehabilitated equipment requires other preventive actions to ensure that they are operating at the expected level of performance and condition. An extra technician and four artisans may added project team. This insinuates that at the beginning of the third month of phase 4, the project team will consist of one engineer, two technicians, and eight artisans.

This project will eventually convert the old plant maintenance department into a modern one with preventive maintenance activities as the main task. It may take two to three years before the modern department is fully established. The main factors are the size of the company, the amount of rehabilitation required, and the manpower available for the project.

b) Project priority: The project should be given high priority among the activities of the technical division. This will enable the project to get the best manpower and working tools available.

c) Change procedures: Changes in any project are inevitable, which may be due to a request from top managers, an unforeseen problem, an unavailability of expected equipment, or transfer of some of the members of the project team, etc. Any change will be explained by an impact statement, which explains the consequences of the change on the technical achievements, completion time, and project costs.

d) Administration procedure: The project manager will report directly to the division manager. In addition, the project manager must have the same status as any other head of the department. The project team will be an inter-disciplinary team and members recruited from various departments under technical division. The members of team will be on the project on temporary terms. But, members from plant maintenance department should stay with the team till the project is converted into a new maintenance department.

At the end of each phase, the project manager will deliver a major report to the top manager of the division which will be the milestone of that phase. The report must include the planned activities, achievements, and shortfalls. Any shortfall must be accounted for, and must explain its effect on the technical achievement, the project completion time, and the project cost.

8.3 Maintenance Organization:

In order to implement the maintenance activities there must be an organization structure which will facilitate its planning and execution. Hence, this section proposes a new organization structure of the whole company, the technical division, and, of the modern maintenance department. The section also suggests a new planning, and a communication system for the modern maintenance department.

8.3.1 Organization Structures:

The proposed organization structure with the main division included is shown on figure 8-1. The main difference between this structure and the present one is the creation of a technical division. In addition, production and plant maintenance departments are under different authorities. Production department is still under the operation division, while plant maintenance is under technical division.

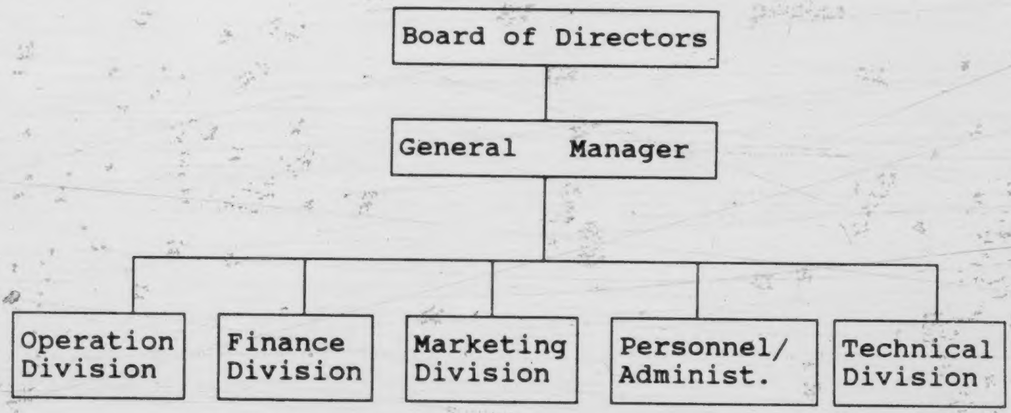

Board of Directors
General Manager
Operation Division
Finance Division
Marketing Division
Personnel/ Administ.
Technical Division

Figure 8-3 New Organization Structure of a Company

The only link between the two departments is through the downtime coordinator. The downtime coordinator is an employee of maintenance department because equipment shutdown affects the production department and other departments as well. Hence, the downtime coordinator is a middleman of maintenance department with other departments.

For the technical division the proposed organization structure is shown on figure 8-4. The organization incorporate a matrix and functional organization structures. In this structure there is a temporary department known as Preventive Maintenance Project (PMP) which is in matrix with other departments. The matrix structure will enable PMP to draw the project team across various departments under the technical division. PMP seems to be a redundant as there is a plant maintenance department, but, it is a modern maintenance department under transition.

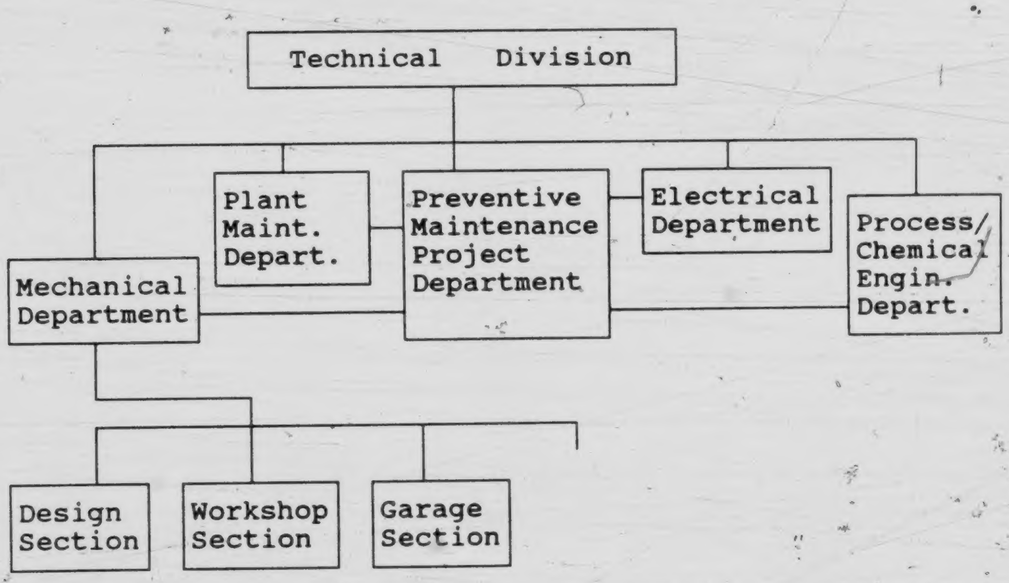

Technical Division
Plant Maint. Depart.
Preventive Maintenance Project Department
Electrical Department
Process/ Chemical Engin. Depart.
Mechanical Department
Design Section
Workshop Section
Garage Section

Figure 8-4 Technical Division Organization Structure

PMP is responsible for all preventive maintenance activities, such as inspections and services, while plant maintenance department is responsible for minor repairs. In a case of a major breakdown, which will require a very long equipment shutdown, the case should be given a top priority by all departments under technical division. Both plant maintenance and project team will work jointly on that equipment. While the plant maintenance is doing failure analysis and repair of the broken part(s), the preventive maintenance project will be doing all major preventive actions on other parts of the equipment.

The organization structure of the modern maintenance department is shown on figure 8-5. Motor vehicle maintenance and building maintenance which are under mechanical and civil departments respectively, are not included in this department. The proposed maintenance department is for plant equipment only. The department consist of six sections: inspection; service; downtime coordination; condition monitoring; overhaul; and a data analysis section. The communication between the sections is both vertical and horizontal depending on the urgency of action required. For example an inspection report should be available to service, data analysis, or overhaul sections depending on what was found on the inspection. This information may flow vertically through the heads of each section, but, when an urgent action is required, it may go directly to the sub-section required to perform the task.

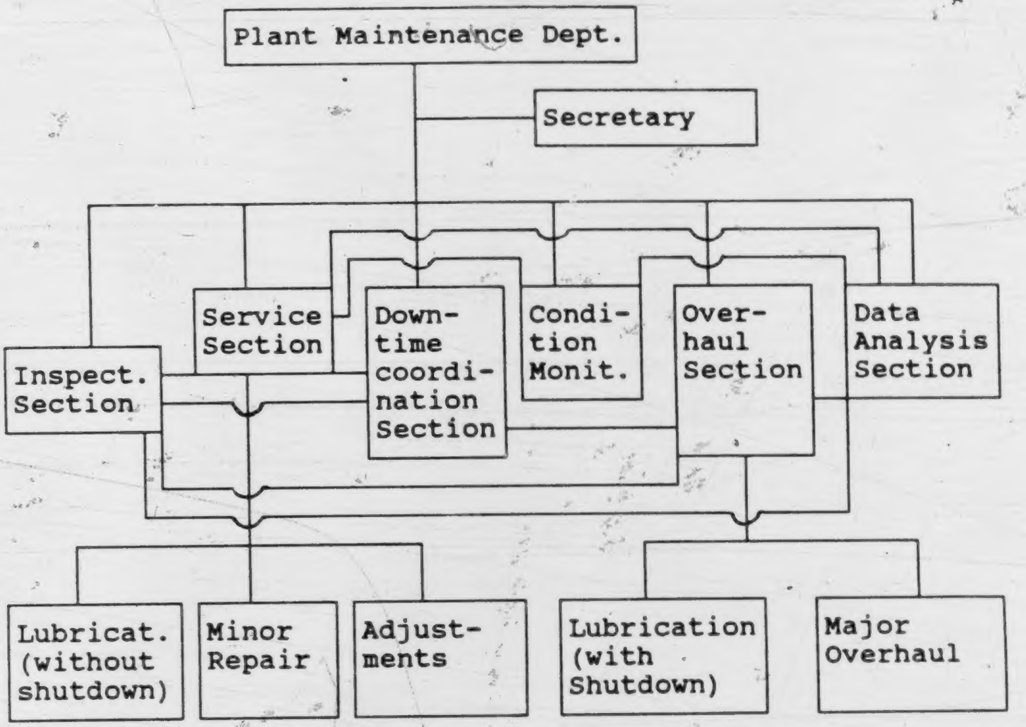

Plant Maintenance Dept.
Secretary
Service Section
Down-time coordination Section
Condition Monit.
Overhaul Section
Data Analysis Section
Inspect. Section
Lubricat. (without shutdown)
Minor Repair
Adjustments
Lubrication (with Shutdown)
Major Overhaul

Figure 8-5 Matrix Organization Structure for Maintenance Department.

8.3.2 Maintenance planning

This section refers to an already established modern maintenance department. Hence, the organization structure proposed on figure 8-5 will be used in explaining the maintenance planning. A centralized planning at the departmental level is recommended. Pre-planned activities for maintenance are mainly three: a) inspection activities; b) lubrication program; and, c) major overhaul activities. Other activities such as minor repair, adjustments, emergency overhaul, etc., are prompted by either inspection, or condition monitoring report, and therefore cannot be preplanned. However, there must be a floating budgeted time and personnel to carry out unplanned activities. The personnel from the Service section may be used to carry out minor repairs (unplanned), while personnel from the Overhaul section may be used to carry out unplanned major repair.

Lubrication program is already discussed in section 7.5.2, so in this section, only planning for inspection and major overhaul will be discussed. Personnel from the Service section are responsible for lubrication programs which does not need shutdown, while major lubrication, which requires a shutdown, may be done during overhaul of the equipment.

The following information for each piece of equipment are prerequisites for any inspection planning: a) a list of parts to be inspected; b) the frequency of each inspection; c) tools required to perform each inspection; d) skilled manpower requirement; and, e) information on whether the inspection must be done while the equipment is running, or while is shutdown. After obtaining required information, the next task is to estimate time required to perform each inspection activity. Time estimates may need a consent of the personnel who will actually perform the job.

Scheduling of inspection activities is the next task after establishing time estimates. Constraints in this scheduling are the availability of skilled manpower, availability of necessary tools for inspection, and the other activities priorities. Priority ranking for equipment mentioned in section 8.2.4.1 may be used in scheduling of inspections. The downtime coordinator may be used to correlate all activities which require equipment shutdown. To reduce the downtime the activities from different sections, which needs shutdown, may be done simultaneously.

Overhaul in some equipment is done once per year, in others once in every two, three, or even four years. Overhaul activities may include a thorough inspection, dismantling of equipment, rebuilding, tuning, and other major activities, which must be done while the equipment is shutdown. In addition to manufacturer's recommendations, the frequency of overhaul depends on the condition of the equipment. A group of one engineer, two technicians, and eight artisans may be given the task of overhauling the equipment. However, if there are many pieces of equipment requiring overhauls, the size of the group may be increased to absorb the extra load.

8.3.3 Spare Parts Management

The maintenance department is responsible for providing information on all spare parts required for both planned and unplanned maintenance. However, the maintenance department may not be responsible for the purchase and keeping of the spare parts. Spare parts stock control is a responsibility of the purchase, or, material requisition department though the maintenance department may assist in updating the spare parts stock. It should be noted that with introduction of preventive maintenance program, there will be a shift in spare parts consumption. There will be a high demand for consumable, and short life spare parts, and low demand for long life spare parts. After each maintenance work, the department should issue a report showing type and amount of spare parts consumed.

8.4 Maintenance Support System:

This section explains devices necessary in carrying out maintenance activities, which are know as maintenance information/support system. Maintenance information system refers to a communication structure within the maintenance department itself, and between the maintenance and other departments. The information system which will be discussed in this section is the card system. The card system may seem antiquated compared to a computerized maintenance systems, but it is still useful for transferring data from the field to a computer data base. In Tanzanian situation, the card system is important for starting a manual data base, which eventually may be transferred into a computerized data base. The Equipment Inventory Card (EIC), and Equipment History Card (EHC) have already been discussed in section 7.3.1, hence, although they are part of the information system, they will not be discussed in this section.

8.4.1 Inspection Card (IC):

An inspection card (figure 8-6) is recommended for each piece of equipment. Each card should explain the items to be inspected, tools required, method of inspection, and acceptability criteria. In addition, the card should leave space for recording inspection results, and for proposed action to be taken.

Methods and procedures of doing preventive maintenance inspections have a great influence on the preventive maintenance program. So, it is important to create a proper inspection method and procedure, in which the inspection can be done in the possible shortest time. Acceptability criteria such as "clearance should be < 0.02mm, oil level should be > 50mm, etc.," are necessary to provide guidelines on inspection tasks. A summary of inspection done on the equipment, and the result of inspection is transferred to equipment history card (ref. fig. 7-3 in chapter 7).

INSPECTION CARD (IC)

EQUIPMENT ID #

INSPECTION CARD #

ITEMS TO INSPECT	TOOLS NEEDED	METHOD OF INSPECTION	ACCEPTABIL. CRITERION	INSPECT. RESULTS	ACTION TO TAKE

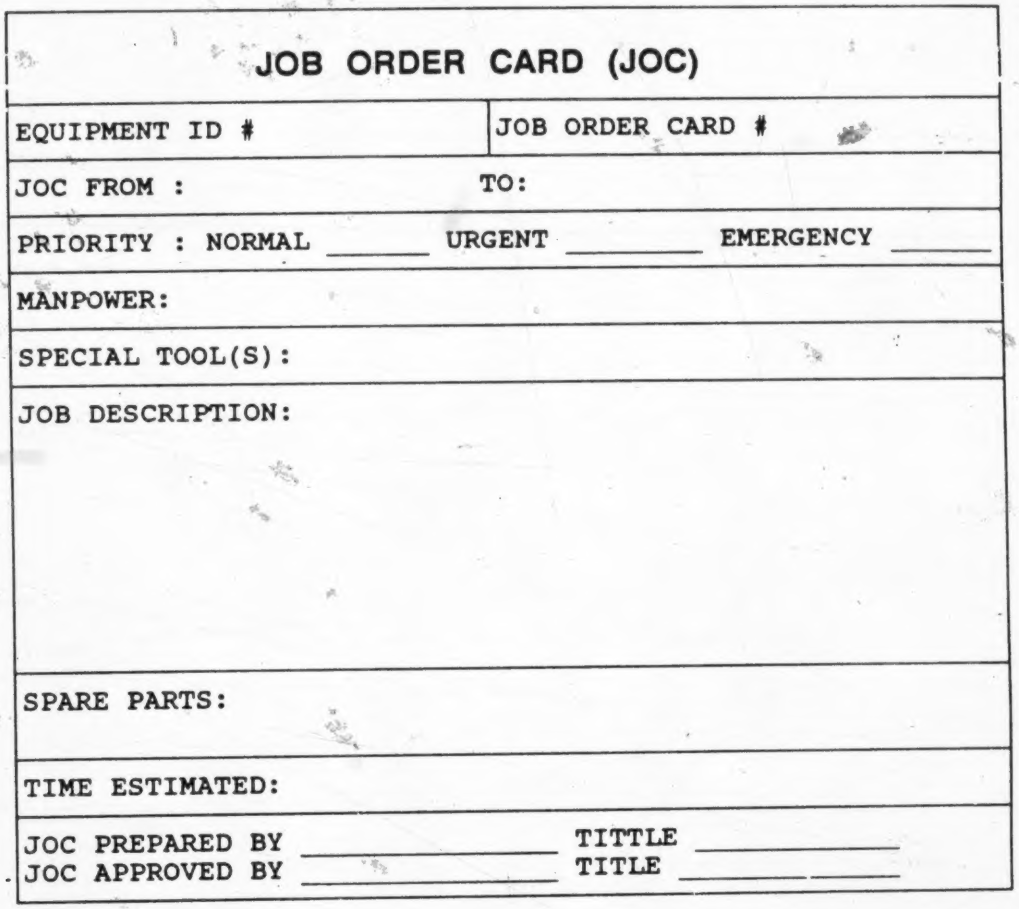
INSPECTION DONE BY ______________ TITLE ________________

ACTION RECOMMENDED BY ___________ TITLE ________________

Figure 8-6: Inspection Card (IC)

8.4.2 Job Order Card (JOC):

A Job Order Card (JOC) (figure 8-7) is issued after an inspection work has be done, after condition monitoring report, or after detecting a breakdown. The card must show the type of work to be performed, the priority of the work, any special tool required, an estimate of manpower and time required to perform the work. Hence, at least a senior technician is required to fill the JOC otherwise it will be difficult for a lower skilled manpower to fill all the required information.



JOB ORDER CARD (JOC)

EQUIPMENT ID # | JOB ORDER CARD #

JOC FROM : TO:

PRIORITY : NORMAL ______ URGENT ________ EMERGENCY ______

MANPOWER:

SPECIAL TOOL(S):

JOB DESCRIPTION:

SPARE PARTS:

TIME ESTIMATED:

JOC PREPARED BY ______________ TITTLE ___________

JOC APPROVED BY ______________ TITLE ___________

Figure 8-7: Job Order Card (JOC)

On the job order card, there are three priority rankings for each work request:

a) Normal priority which applies for routine scheduled works. It may also be issued after a scheduled inspection activity in which minor deterioration has been detected. The work requested may be performed in two days after the issuance of the order.

b) Urgent priority which applies for preventive maintenance work which must be done at once otherwise failure is likely to occur. The urgent priority imply that a preventive action is required in one day time. The urgent priority also apply for a critical equipment which for failure cannot be tolerated. The urgent priority should be issued for critical equipment, even if the deterioration detected is very minor.

c) Emergency priority is issued just as a matter of formality as it is issued after failure has occurred. In that case, the JOC will be prepared on the site while the work to restore the broken part is in progress.

8.4.3 Maintenance Work Card (MWC):

The maintenance work card (MWC) (figure 8-8) is issued after maintenance work has been performed and is a useful tool in maintenance report writing. The card should show the real time used in doing the maintenance work, manpower utilized, spare parts used, state of the equipment after the maintenance work, and planned future work. A summary of information in this card is transferred to the EHC (figure 7-3), the summary must explain the type of breakdown and the amount of spare parts used. In addition, the information in this card which concern spare parts, may be conveyed directly to material requisition department for updating the spare parts inventory.

<table>
<tr><td colspan="5">MAINTENANCE WORK CARD (MWC)</td></tr>
<tr><td colspan="2">EQUIPMENT ID #</td><td colspan="2">ISSUED AFTER JOC #</td><td>MWC #</td></tr>
<tr><td colspan="5">DESCRIPTION OF WORK PERFORMED:</td></tr>
<tr><td colspan="5">STATE OF EQUIPMENT AFTER THE WORK:</td></tr>
<tr><td colspan="5">LIST OF SPARE PARTS USED:</td></tr>
<tr><td>1
2</td><td>3
4</td><td>5
6</td><td>7
8</td><td>9
10</td></tr>
<tr><td colspan="4">MANPOWER UTILIZED</td><td>TOTAL TIME USED (hrs)</td></tr>
<tr><td colspan="5">RECOMMENDATION:</td></tr>
<tr><td colspan="5">PREPARED BY ____________ TITTLE ____________
APPROVED BY ____________ TITTLE ____________</td></tr>
</table>

Figure 8-8: Maintenance Work Card (MWC).

8.4.4 Maintenance Report Format:

The maintenance report format (figure 8-9) is intended to create a uniformity in presenting the maintenance reports. The format will prompt the writer to include every detail required, which without a report format would be omitted. Every section in maintenance department should deliver a detailed report to the head of the department at least once per week. The head of the department should also once per week deliver a concise report to the manager of the division. Important items which must be included in each report are: manpower utilized; spare parts consumed; downtime; and, planned activities for the following week.

MAINTENANCE REPORT

WEEK ENDING mm/dd/yy ____/____/____

FROM: (Section)__________________________

TO: Head, Maintenance department

THIS WEEK ACTIVITIES:

EQPMT ID #	WORK PERFORMED	MANPOWER	SPARE PARTS	DOWN TIME

NEXT WEEK'S ACTIVITIES

PREPARED BY ________________ HEAD OF THE SECTION

Figure 8-9: Maintenance Report Format

9.0 Conclusions and Recommendations:

9.1 Conclusions:

In problem definition (refer chapter 2), the following major conclusions were encountered:

i) maintenance is pervasive and serious problem in many Tanzanian industries;

ii) the modern type of industry in Tanzania is a relatively new phenomenon. Hence, some of the industrial problems are due to its newness to the Tanzanian society; and,

iii) some of the maintenance problems may originate from a sudden shift from a capitalist to a socialist mode of production.

The analysis of the maintenance problems, in Tanzanian industries, shows that the problems are so diversified that it is very difficult to classify them into few major groups. However, the following maintenance problems are more visible in almost each Tanzanian industry:

i) the problem of skilled manpower - there is a scarcity of engineers and qualified technicians to run the industries;

ii) the spare parts problem - there is a mismanagement of spare parts; lack of technology and equipment to manufacture the spare parts; and, difficulty in spare parts procurement;

iii) maintenance organization problem - it seems that there are poor maintenance management systems in many Tanzanian industries;

iv) top management support - the analysis shows that top management either is ignorant of the importance of maintenance, or does not provide the necessary and/or adequate support to the maintenance department;

v) lack of Maintenance Culture - maintenance is not well understood by the majority of Tanzanians, which is manifested by the national language Swahili, in which there is no equivalent term for maintenance and related terms such as availability and reliability;

vi) appropriate technology - it seems that Tanzanians lacks the necessary knowledge to choose the appropriate technology for their environment;

vii) there is a lack of necessary facilities such as workshop, foundry, heat treatment facilities, etc., to support maintenance; and,

viii) record keeping - the majority of the industries confessed that they don't keep records of the maintenance activities.

In the questionnaire analysis, the maintenance personnel in Tanzanian industries assert that their major problems, which restrain their maintenance activities, are scarcity of spare parts and skilled manpower. But, a detailed analysis of the maintenance problems revealed that, the major problems are within the organization structures of the industries and management of the maintenance activities. The maintenance departments are in inferior positions in organization structures, which cause difficulties in implementation of the maintenance programs.

9.2 Recommendations:

The following recommendations, which are in three categories, are intended to alleviate the present maintenance problems in Tanzanian industries:

a) recommendations aimed at alleviating the spare parts problem;

b) recommendations for reducing the scarcity of skilled manpower in the technical field; and,

c) recommendations for implementing the maintenance model proposed in chapter 8.

In analyzing the maintenance problems in Tanzania it was found that, problems of spare parts and skilled manpower are beyond the mandate of an individual industry. However, if each industry put forth enough effort to reduce these two problems, the maintenance situation in Tanzanian industries would be improved from the presently. A joint effort to tackle the two problems is recommended over the efforts of an individual company.

9.2.1 Spare Parts:

It is recommended that industrialists should put forth efforts to acquire spare parts locally. During the planning period the industrialists should advertise for their spare parts requirements for the whole year. The advertisement may be either in a tender form, or, just a simple advertisement in local media. Different spare parts manufacturers and dealers may present their bid to supply the company with the required spare parts. This will reduce the hassle of searching for the spare parts by the industrialists themselves. In addition, the companies could get cheaper spare parts by using supplier(s) than each individual company trying to import small quantities of spare parts they need.

It was also shown that, industrialists are reluctant to use locally made spare parts because of their quality. The local spare parts manufacturers should improve the quality of their spare parts before advertising that their spare parts are as good as imported ones. After producing high quality spare parts, and, making adequate promotion, the present attitude of the industrialists could be changed. In addition, local spare parts manufacturers may counter the advertisements which show that genuine spare parts are only those from the "Original Equipment Manufacturers (OEM)". Advertisements such as, "our spare parts are as good as any imported ones; they are cheaper and easily available; why pay more; why get frustrated by unavailability of spare parts; come to us; etc.", may change the present market for local spare parts. In addition, the government may play a part to make the industrialists use the local spare parts by increasing restrictions on importation of spare parts.

Lack of advertisements, and the small size of the local spare parts manufacturers are among the main problems in the local spare parts market. The largest promotion which have ever taken place is when the president of Tanzania decided to make a random survey of the local spare parts manufacturers. His aim was to explore the potential spare parts manufacturers for cotton ginneries which were in great need. The president found that there was a very potentially large source of spare parts within the country [60].

What is required now is to make a detailed feasibility study to explore the capabilities of the local engineering workshops to manufacture spare parts. In addition, it is essential to conduct a detailed market study to establish the amount and type of spare parts needed (size of the market), the growth rate of the market, and the big players in the market. But, since these engineering workshops are very small, it will be too difficult and expensive for an individual company to make a thorough market study.

However, a joint effort by various groups of companies could conduct a detailed market study to investigate the size of the market and its segments. Thereafter, the next step is to distribute the market segments among themselves in order to avoid unreasonable competition in one segment while leaving the other segments unexplored. For example, after establishing the size of the spare parts market and its segments, one company could concentrate on manufacturing auto spares, another company on textile industry spares, another on cotton ginneries, and so on. Another parallel market study required is to explore the capacity and capability of each engineering workshop and tally out with market segments' requirements.

In addition, one way of reducing the scarcity of spare parts is by implementation of the preventive maintenance model proposed in this thesis. The preventive maintenance program will reduce breakdowns, in that case, the demand for breakdown spare parts for unplanned maintenance will be reduced. With improvement in preventive maintenance system, the consumption of cheap spare parts such as bearings, oil filters, and other consumables, will increase; but, the demand for durable spare parts will decrease. With an effective preventive maintenance program, it is possible to plan for replacement of consumables. So, the only other requirement will be a good spare parts inventory system.

The spare parts problems in Tanzania is a very broad topic. If fully dealt with, it could produce another thesis of its own. Thus, it is recommended to make an analysis of the spare parts situation in Tanzania, with aims of exploring: a) the current need of spare parts in Tanzania;

b) the capacity (amount) and capability (technology) of existing engineering workshops to produce spare parts;

c) annual consumption of raw material in spare parts manufacturing alone;

d) annual costs to manufacture spare parts; and,

e) annual costs of importing spare parts.

9.2.2 Skilled Manpower:

The scarcity of engineers in the country in general may be a serious problem. In addition to the fact that many highly trained personnel are fleeing the country and the fact that only 0.05% of those who complete primary education eventually become engineers it is still questionable that the few available engineers are fully utilized. In addition to their normal duties, the few available engineers could be used to educate the artisans by conducting evening classes. The following courses could be suitable for the artisans: safety engineering; maintenance management; engineering drawings; english; mathematics; labour management; machining; welding; forging; foundry; and, auto-mechanics.

In addition to the general courses mentioned above, the artisan may be given "customized training". Moss [98] defines customized training as, "the training specifically designed for a particular firm; it is tailor-made for a given time, and, group of workers within the firm". The aims of the training should be:

a) to increase the efficiency of work performance;

b) to increase the artisans' knowledge;

c) to improve good work relationships; and,

d) to help the artisan understand the principles of modern maintenance management.

9.2.2.1 Curriculum for Artisan Education:

After graduating from a trade school, an artisan is equivalent to a form four leaver (refer to figure 7-1); the only difference is in the curriculum of their training. The following curriculum may be used to teach the courses mentioned above.

A) Safety Engineering:

The aims of this course are: to increase the safety awareness of an artisan; to improve safety at the work-place; and, to teach the artisan their rights in relation to safety. The subjects to be taught in this course include:

i) occupational hazards;

ii) safety liabilities;

iii) personal safety;

iv) equipment safety;

v) fire - causes of fire, types of fires, types of fire extinguishers, what to do in case of industrial fire, etc.;

vi) good house keeping; and,

vii) chemicals - handling of hazardous chemicals and their disposal.

B) Maintenance Management:

The course should be focused on showing the importance of preventive maintenance. The subjects to be taught in this course may include:

i) types of maintenance -the advantages and disadvantages, and appropriate application of each type;

ii) inspections -different types of inspections, importance of inspection, reading of inspection tools, and test procedures;

iii) services -the importance of regular equipment service, different types of services, importance of lubrication, different types of lubricants and their applications, reading of dipstick, and implementation of lubrication program; and,

iv) fault diagnosis - use of maintenance manual in fault diagnosis and fault isolation, and, use of technical trouble shooting model.

C) Engineering drawings:

The intention is to enable an artisan to read the most commonly used engineering drawings. The following subject may be taught under this course:

i) machine drawings - assembled drawings with hidden details, blown-out drawings, machine elements drawings, and installation drawings;
ii) electrical drawings - commonly used electrical symbols and circuital drawings; and,
iii) fluidics -pneumatic and hydraulic drawings.

D) English:

English is one of the most highly used language in the world and most of the maintenance manuals are written in English. The course should therefore be aimed at enabling an artisan to read and understand instructions written in English. The course may include:

a) English grammar;
b) reading comprehension; and,
c) technical vocabularies.

E) Labour management:

The intention of this course is to develop a good working relationships among the artisans and between the artisans and management. In addition, the labour psychology (although it will be just an introduction) will improve good behaviour in the work-place. The following subjects may be taught in this course:

i) managerial psychology - labour behaviour, group dynamics, mob behaviour, and motivation theories; and,

ii) labour laws - introduction to labour laws, employers legal rights, and employee legal rights.

F) Mathematics:

Mathematics should be taught to enable the artisan to work with simple mathematical formula. In maintenance manuals, services must be done following certain dimensions. Some of those dimensions are written either in formula form or must be converted from one unit to the other. While simple arithmetics may be enough for most of the artisans, the details of the subject should depend on the type of work the artisan is supposed to do.

G) Machining:

The aim is to improve the machining knowledge of artisans. In addition, the theories behind machining procedure may be introduced in this course. The subjects to be taught under this course may include:

i) operational procedure;

ii) simple machining dynamics;

iii) machine set-up;

iv) sharpening of cutting tools; and,

v) an introduction to computer-aided machining (CAM).

H) Welding:

The aim is to increase the artisans' knowledge of different types of weldings and their applications. The subject may include electrical arc welding, mercury inert gas welding (Mig), tungsten inert gas welding (Tig), oxy-acetylene gas welding, and spot welding.

I) Foundry and Forging:

Artisans should be aware of alternatives in manufacturing spare parts (foundry and forging is an alternative way of manufacturing spare parts). The course may include an introduction to the theory and application of foundry and forging technologies. In addition, training in mould making may be taught in detail to enable the artisans to produce their own moulds.

J) Auto-mechanics

The course should be aimed at teaching the artisan service and repair of motor vehicles. The following subjects may be taught under this course:

i) repair and servicing of engines;
ii) auto-electrical system(s);
iii) transmission and brake systems; and,
iv) autobody repair;

For a company which does not have even a single engineer, an external consultant may be hired to design and install the maintenance system. The same consultant may be asked to train the artisan to maintain the installed system. In Tanzania, the following institutions offer consultant services to industries: the University of Dar es Salaam (UDSM); Tanzania Industrial Research and Development Organization (TIRDO); and, Metal Engineering Industries Development Association (MEIDA).

9.2.3 Implementation of the Model:

For a smooth implementation of the maintenance model discussed in chapter 8, the personnel who will be affected by the changes should be made ready to accept the change. Top management, production, and maintenance will be the first personnel to feel the changes. It is quite natural for people to feel anxiety towards impending change and this anxiety produces different reactions in different people such as resistance. However, if the people are well prepared for the change, resistance will be minimal. Education is one of the best ways of dealing with resistance to change.

A one day seminar may be enough for top management, while a one week training course is needed for production personnel. For maintenance personnel, a one day seminar is necessary to introduce the model but the real maintenance training will be a continuous process during implementation. The main intents of the seminars will be to give the workers assurance that their employment, and work relationship will not be jeopardized by the changes.

9.2.3.1 Seminar for Top Management:

The seminar should prove that the overall production costs can be reduced by improving maintenance management. The following topics should be discussed.

i) Maintenance management:

different types of maintenances and their applications;

ABC of failure analysis, costs of failures in relation to direct costs, lost production, and safety of personnel and of equipment; and,

maintenance cost accounting.

ii) Maintenance organizations:

maintenance information systems;

maintenance reports and their implications; and,

responsibility of top management in maintenance programs.

iii) Relationship between maintenance and production:

equipment availability and reliability;

planning, control, and coordination of downtime; and,

equipment operating condition.

9.2.3.2 Seminar for Operation Personnel:

The seminar should be aimed at showing the operational personnel the proper equipment operating condition. EEUA [99] observed that, operators are hesitant to report equipment malfunction because some of the malfunctions are due to equipment abuse. Hence, another way of minimizing equipment failure is to increase the operators' skill. In addition, operators should be educated to report any change in the operating condition of the equipment as soon as they detect them. It is possible to stop failure if it is detected early enough to take a preventive measure. The following subjects should be discussed at the seminar:

a) machine set-up;
b) machine operating baseline;
c) failure symptoms; and,
d) failure reporting.

9.2.3.3 Seminar for Maintenance Personnel:

Maintenance personnel will be the most highly affected personnel in implementing the maintenance model. Hence, it is important to conduct a one day seminar to explain the reasons for the modifications, the effect of the changes on their work, and the security of their employment. To avoid resistance, it is important to assure the maintenance personnel that nobody will be made redundant due to the impending re-structure.

At the seminar, the maintenance personnel should be asked to suggest ways of implementing the preventive maintenance model. This implies that the project manager should be flexible enough to take the suggestions from the common personnel. Making the maintenance personnel take part in planning the implementation strategies is another way of minimizing the resistance to change. Recommendations from the maintenance personnel should be analyzed and documented, the feasible ones should be implemented at once.

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11.0 Appendices:

11.1 Appendix 1 The Questionnaire:

1. What is the official name of the company?

2. Postal
address: ____________________

____

Phone Number ____________________

Telex Number: ____________________

Town/City: ____________________

3. Ownership of the company is:

4. What is the size of the company? (approximate number of employees)

5. What is the type of your company? (Textile, steel industry etc)

6. What are the product of your company? (eg. clothing, hoe etc)

7. At what capacity is your company working at present time?

8. What is the recommended working capacity?

9. If the working capacity is below the recommended one: What are the problems?

10. Is any of the following affects your capacity utilization?

A). Water shortage	YES	NO
B). Power/Electricity shortage	YES	NO
C). Frequent machine breakdown	YES	NO
D). Lack of spare parts	YES	NO
E). Raw materials	YES	NO
F). Market	YES	NO

11. How do you rank the above problems ?

12. What are the types of your machinery and/or equipment?

Machine type	Year (of manufacturing)

13. List the classes of equipment and the types of the maintenance programs that exist for each equipment.

.eg. vehicles...........breakdown maintenance

(cont of quest # 13)

14. How many failures do you experience each weak?

Average	High	Low
________	_______	________

15. What is the average repair time for each type of machine? (give an example of a common failure and its repair time)

16. How much does it cost (in terms of lost production) per hour when there is such a failure?

17. Please estimate the current availability of your machines and/or equipment

18. What is the manufacturer's recommendation for availability of machines/equipment?

19. Do you carry out a shutdown maintenance? YES NO

If yes, how long does it take?

Estimate the cost for the shutdown maintenance in Tshs.

20. What is the main source of your spare parts?

21. What is the main problem (if any) concerning the availability of your spare parts?

22. By what percentage can you produce spare parts in your company's workshop?

23. What are the problems (if any) you are facing in manufacturing your own spare parts?

24. What is the source of raw materials you are using in manufacturing your own spare parts?

25. Mention a few of your spare parts which you have to import from abroad and if possible comment on why you have to import them?

26. Do you have an access to foreign currency? YES NO

27. What priorities does your company have in foreign currency allocation according to government policy?

28. Do you export any of your products?

29. Do the recent trade liberalization help your company or adversary affect your company?

30. How well equipped is your workshop? Please mention the type of machine tools and equipment you have:

machine/equipment	type	country	year of make
eg. Lathe	Gildmare	W.Germany	1967
Welding Generator	Suzuki	Japan	1983 etc

31. Please give a summary of your maintenance workforce qualification.

QUALIFICATION	NUMBER
Graduate Engineers	
Diploma Holder Engineers	
Technicians	
Artisan	
Others (eg On Job Trainees)	

32. What are the main problems you are facing in carrying out your daily maintenance activities?

33. What is the estimate total capital cost of your production equipment?

34. How much do you spend annually on spare parts?

35. What is the total value of your annual production?

36. What is the total annual cost of your maintenance department?

37. Do you feel that your maintenance department is:

Too large

Just right

Too small

38. Will the improved maintenance systems help to improve your capacity utilization? YES NO

39. Any other comment

************ THANK YOU FOR YOUR CO-OPERATION ************

11.2 Appendix 2 Organization Structures:

In this appendix, organization structures of various Tanzanian industries are presented with an intention of showing the position of maintenance departments in those industries. As shown on figures 11-1 & 11-2, maintenance and production departments are under the same division. In most cases, the top manager is more concerned with production than maintenance (because it is the main objective of the company), so, the head of the division would also be more interested in production than in maintenance. In that situation maintenance suffers, it would better to put the plant maintenance under technical services division, which would be a separate entity without production department. Technical division may include the following departments: engineering; workshop; garage; etc.; but not production. The production department can then be under the operation division which may include marketing, finance, and purchasing, but not maintenance. Production and maintenance activities have a lot of interference, in many cases, when maintenance activities are being executed, production activities have to be stopped, and vice versa.

The first organization structure to be analyzed is that of Ubungo Farm Implement Company (UFI). In this organization structure, there is no operation division but there is a technical division headed by a technical manager. Under the technical division there are production, design & development, and, maintenance & workshop departments [87]. Since the technical manager is an engineer, one would expect that the department would be more technical oriented, and, hence maintenance would be given more attention. But the main question is, "what type of report the top manager is more interested to see?" It is obvious that the top manager would be more interested in the production report from the technical division than any other type. The technical manager has to dance according to the drum beats and consequently the technical manager would also be more interested in the production report than maintenance report. So, even in this type of organization structure, maintenance activities would still suffer.

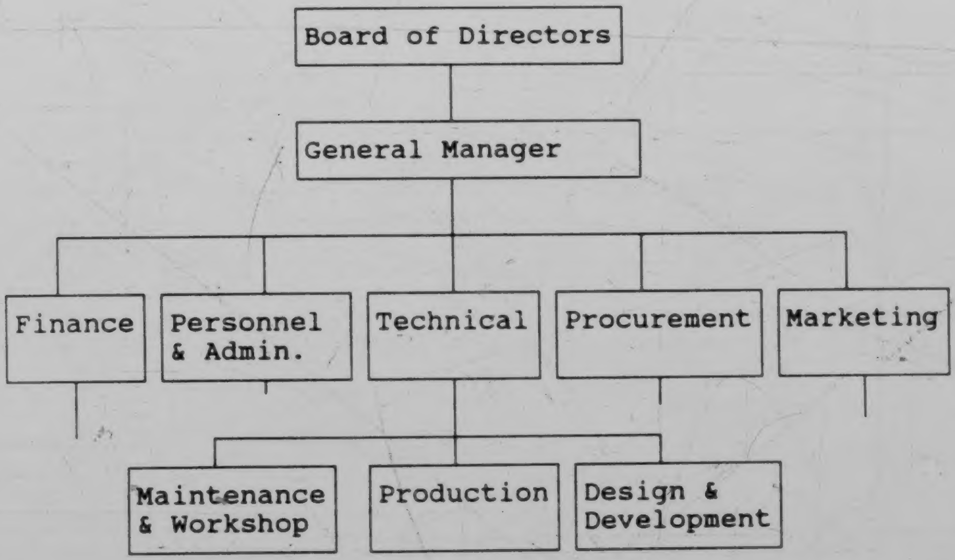
Board of Directors
General Manager
Finance
Personnel & Admin.
Technical
Procurement
Marketing
Maintenance & Workshop
Production
Design & Development

Figure 11-1: UFI Organization Structure

The second organization structure to be presented is that of Tanzania Portland Cement Company (TPCC). In TPCC, unlike UFI, the maintenance department is under operation division with three other departments: production; materials; and, quality control [88]. In the case of UFI, the head of the technical division must be a technical personnel, but, in the case of TPCC, the head of the division may not be a

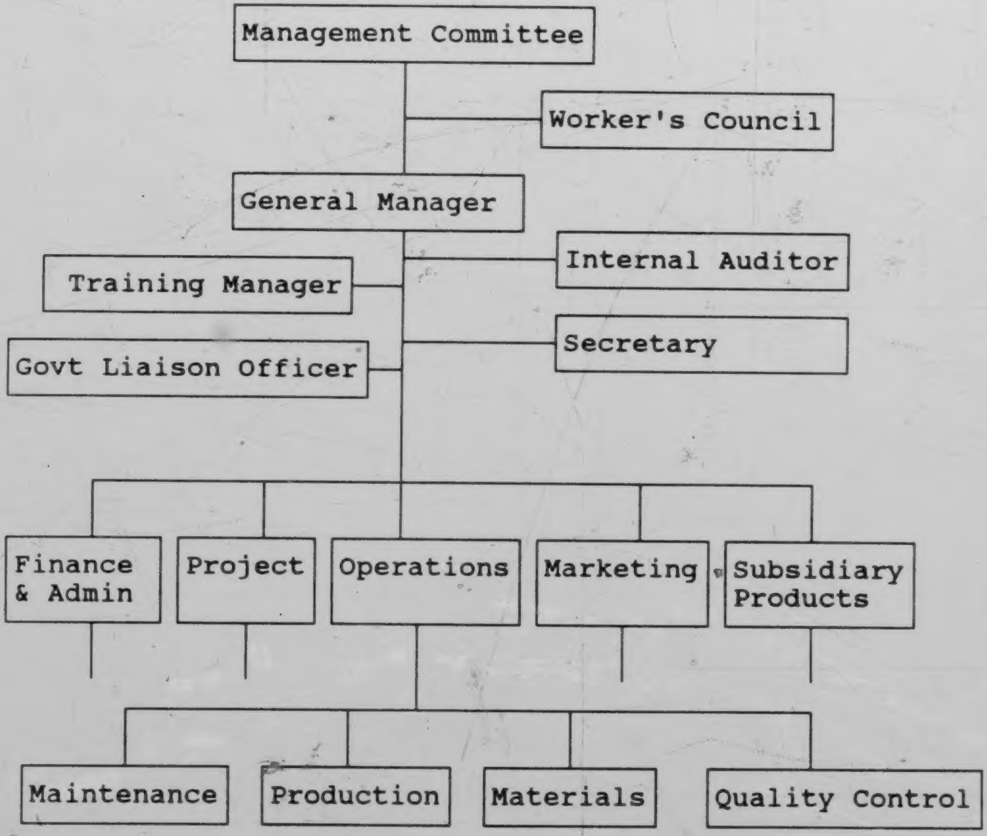
Management Committee
Worker's Council
General Manager
Internal Auditor
Training Manager
Secretary
Govt Liaison Officer
Finance & Admin
Project
Operations
Marketing
Subsidiary Products
Maintenance
Production
Materials
Quality Control

Figure 11-2: TPCC Organization Structure

technical personnel. Though it is not necessary that if the head of division is a technical personnel then maintenance activities will be given more attention, but still it makes a lot of difference. The technical personnel is more cognizant with the technical terms used in maintenance and other technical reports. Hence, it would be easier for a technical personnel to understand the maintenance report, and to give constructive appraisal. On the other hand, a non-technical head of operation division may not understand the maintenance report, especially, in Tanzanian situation in which people have very crude ideas about preventive maintenance.

The third organization structure to be discussed is that of Zana Za Kilimo (ZZK), a farm implement manufacturing company based in Mbeya, south-west of Tanzania. The company has only four divisions, each headed by a manager: material; production; marketing; and, administration. The organization structure in this company is quite different from those of UFI and TPCC. There is no maintenance department as a separate entity of itself, but it is parcelled into two departments of mechanical and electrical, and all of them are under production division. This is the worst case among the three cases discussed in this appendix. The production division has a total of eight departments, including the two mechanical and electrical maintenance departments. In this situation, it is more likely that maintenance programs are less important than technical personnel. Though it is not necessary that if the head of division is a technical personnel then maintenance activities will be given more attention, but still it makes a lot of difference. The technical personnel is more cognizant with the technical terms used in maintenance and other technical reports. Hence, it would be easier for a technical personnel to understand the maintenance report, and to give constructive appraisal. On the other hand, a non-technical head of operation division may not understand the maintenance report, especially, in Tanzanian situation in which people have very crude ideas about preventive maintenance.

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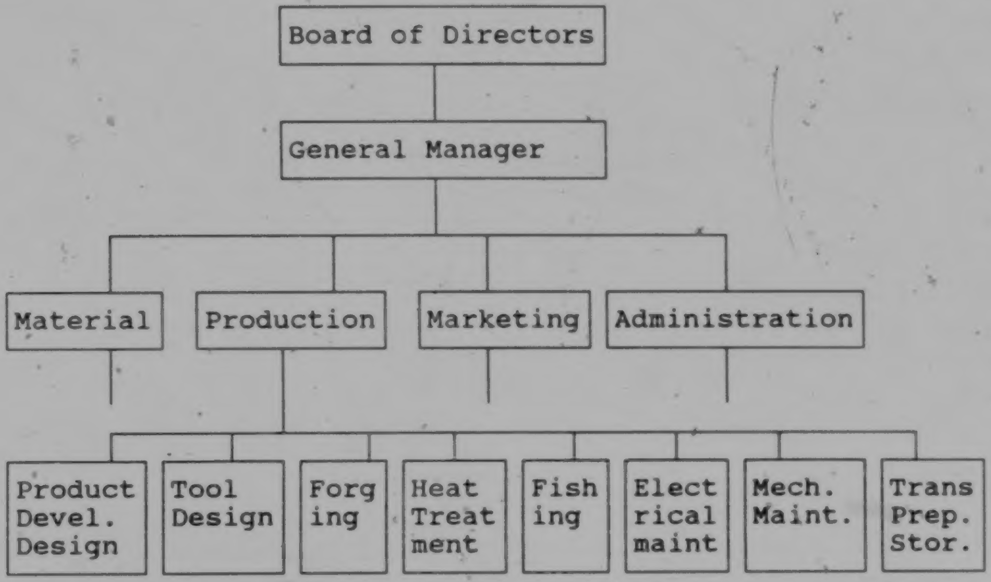

Board of Directors
General Manager
Material
Production
Marketing
Administration
Product Devel. Design
Tool Design
Forg ing
Heat Treat ment
Fish ing
Elect rical maint
Mech. Maint.
Trans Prep. Stor.

Figure 11-3 ZZK Organization Structure

The three organization structures discussed, represent many other organization structures in Tanzanian industries. The only difference is the names of divisions in different companies but functionally they are almost the same. Almost all put the plant maintenance department under the umbrella of, or under the same umbrella with, the production department. A detailed study of the effect of the present organization structures, on maintenance activities in these companies, may reveal many other problems which hitherto are unknown.

11.3 Appendix 3 Maintenance-Computer Application:

Computer technology has rapidly developed over the past few years. In developed countries, computer applications have been accepted in almost every area of business. A computer survey, made by Sunday News Tanzania, indicated that computer technology is entering Tanzania at a very high speed [100]. Hence, it is time now for maintenance managers in Tanzanian industries to pursue computerization of maintenance activities. But before starting of the computerization of maintenance activities, there are some fundamental issues which must be determined.

The first issue to be resolved is "What type(s) of Computer system the company has or is willing to buy?" There are three main computer categories: mainframe which is high speed, big core-storage and uses time sharing multi-users system; minicomputer which is also multi-user system but less core-storage than mainframe; and microcomputer which is a single user system, small speed and small core-storage. The three systems are distinguished by their speed, number of simultaneous users, core-storage, and type of software. But with the recent development of high speed, high capacity micros, and local area network (LAN) systems, it is difficult to demarcate mainframes, minicomputers, and microcomputers [101]. Mainframe computers are more suitable for large organization, while mini and micro computers are more suitable for medium and small size industries.

Maintenance application softwares on the market are also divided according to the three categories of computers mentioned. The cost of individual software somehow depends on its application and the system to be used (mainframe, minis, or micros). Microcomputer based maintenance software are the cheapest but they may not have as many applications as the mainframe based softwares. Hence, the second issue to be settled is the company's need. The maintenance managers should develop management and control systems that suit their organizations, and then select the softwares that fit the needs of the system.

For maintenance softwares, the following requirements may assist maintenance managers in drafting their own requirements [102]. Automatic scheduling of activities, activities updating, backlog information, equipment history, equipment tracking for multi-location company, equipment inspection procedures, maintenance failure analysis, maintenance cost analysis, work smoothing facilities (labour requirement smoothing), on-line link to spares (inventories, updates, etc.), facilities for printing emergency work order, reporting capabilities (major reports, ad-hoc reporting, ad-hoc analysis), drawings and manuals, equipment operating condition, and on-line multi-user information.

In addition to the maintenance requirements, there are other general software requirements which make one more appeasing than another. A survey of 1900 data processing managers, responsible for buying and evaluating softwares, was conducted by Sentry Market Research in conjunction with the **Software Magazine** [103]. The managers were asked to rank their software selection criteria in order of importance, the findings are summarized in table 11-1.

Commercially available maintenance software survey was conducted by Bamford and Kelly [104]. The survey included the cost of the software, its basic features and the cost of the hardware. But the survey did not include the cost of resources required for setting up the maintenance plan, information base, etc., which are very vital for implementation. The survey is summarized in table 10-2.

Table 11-1 Software selection Criteria

Selection Criteria	Mainframe	Minicomputer	Microcomputer
Ease of use	67%	75%	73%
Features and performance	69	65	66
Documentation	63	63	66
Vendor support	67	51	39
Compatibility with other SW	48	49	46
Error handling	39	33	35
Compatibility to other hardware	25	30	32
Vendor size and reputation	25	18	17
Price	26	22	20
Site licensing	--	--	16
Removal of copy protection	--	--	31
Limited liability for unauthorized copying	--	--	7
Ability to transfer programs between mains, minis and micros	--	--	22

(figures are percent of respondents claiming the criteria was 'very important', SW = Software)

Table 10-2 Commercial maintenance software packages

	Name	WIMS	COMPASS	COMAC	SAMSON
	Supplier	ABS	Bonner & Moore	Comac	Davy
	Micro/Mini	MINI	MINI	MICRO	MICRO
	Computer	ABS MX	Data General	Commodore Pet	Any
	Hardware cost	£18,000	£200,000	£2,000	£10,000
	Software cost	£ 5,000	£100,000	£3,000	£15,000
INFO BASE	INVENTORY	Y	Y	Y	Y
	TECHNICAL INFORMATION	N	Y	N	Y
	DRAWINGS AND MANUALS REF	N	Y	N	Y
	ON-LINE LINK TO SPARES	Y	Y	N	Y
	INFORMATION ON REPAIRABLE ITEMS	Y	Y	N	Y
PM	JOB CATALOGUE (J.C) OR UNIT SCHEDULES	J.C	J.C	U.S	J.C
	(U.S) WORK SMOOTHING FACILITIES	N	N	N	N
WORK PLAN	MINIMUM WORKING PERIOD	Week	Day	Week	Day
	FACILITY FOR WORK ORDER PRINT	Y	Y	Y	Y
	FACILITY FOR PRINT EMERGENCY WORKORDER	N	Y	Y	Y
	FACILITY FOR BACKLOG REPROGRAMMING	N	N	N	Y
	ANALYSIS OF WEEKLY WORK ORDERS	Y	Y	N	Y
CONTROL	HISTORY RECORD	Y	Y	Y	Y
	ON-LINE SEARCH AND ANALYSIS	Y	Y	Y	Y
	TOP-TEN	Y	Y	N	Y
	COST CONTROL	Y	Y	N	Y

(continued on the next page)

Continuation of table 10-2

SAMSON	I.B.M	MMS	PAMIS	TEROMAN	CAMS
Davy	I.B.M	MMS	P.A. Consul.	Scicon	Vosper Thorneycrof
MINI	MINI	MICRO	MICRO	MINI	MINI
HP1000	8100	Any CP/M	AnyCP/M	HP3000	PDP/VAX
£70,000	£ 70,000	£5,000	£ 7,000	£80,000	£ 15,000
£50,000	£ 30,000	£8,000	£15,000	£70,000	£ 25,000
Y	Y	Y	Y	Y	Y
Y	Y	Y	N	Y	Y
Y	Y	Y	N	Y	Y
Y	Y	Y	N	Y	Y
Y	Y	Y	N	Y	N
J.C	No PM	U.S	J.C	J.C	J.C
N	N	Y	N	N	Y
Day	Day	Day	Week	Day	Day
Y	Y	Y	Y	Y	Y
Y	N	Y	Y	Y	Y
Y	N	Y	N	N	Y
Y	N	Y	Y	Y	Y
Y	N	Y	Y	Y	Y
Y	N	Y	Y	Y	Y
Y	N	Y	N	N	N
Y	N	Y	N	N	Y

Continuation of table 10-2

SCOMAG	ICL	MPMS	
Scomag	ICL	Microtech	
MINI	MINI	MICRO	
PDP11	2903,ME29	Any	
£20,000	£ 30,000	£3,000	
£12,000	£ 11,000	£ 500	
Y	Y	Y	
Y	Y	Y	
N	N	Y	
Y	Y	Y	
N	Y	N	
J.C	J.C	U.S	
N	N	N	
Day	Day	Day	
Y	Y	Y	
Y	N	N	
Y	Y	N	
Y	Y	Y	
Y	Y	Y	
Y	Y	Y	
Y	Y	N	
Y	Y	Y	

11.4 APPENDIX 4 Normal Distribution:

Normal distribution is a symmetrical distribution function, that is described by mathematical functions, deduced when the principle of pure chance is applied to a population of infinite size. If $x_1, x_2, \ldots, x_N$ are recorded failure values (eg. operating hours, operating cycles, etc., before failure), then the Normal distribution, being a symmetrical distribution, can be described by its mean and standard deviation. The mean of a normal distribution is defined as:

$$\overline{x} - \frac{\sum_{i-1}^{N} x_i}{N} \qquad 11.1$$

Standard deviation is the measure of dispersion, which is a root-mean-square of the deviations from the mean, of all values in the population. The standard deviation is denoted by a 'σ' where:

$$\sigma - \sqrt{\frac{\sum (x_i - \overline{x})}{N}} \qquad 11.2$$

On statistical books N-1 is normally used as denominator instead of N, but as the size of the data increases, this error becomes negligible. The probability distribution function is then defined as f(x) where:

$$f(x) = \frac{1}{\sigma\sqrt{2\Pi}} \exp -\frac{1}{2}\left(\frac{x-\bar{x}}{\sigma}\right)^2 \qquad 11.3$$

where (x-xbar) is a deviation from the mean. The cumulative probability function F(x) is given by

$$F(x) = \frac{1}{\sigma\sqrt{2\Pi}} \int_{-\infty}^{x} \exp\left[-\frac{1}{2}\left(\frac{x-\bar{x}}{\sigma}\right)^2\right] dx \qquad 11$$

Expression 11.4 can be simplified by the so-called standardization of the normal curve by doing the following substitution:

$$u = \left(\frac{x-\overline{x}}{\sigma}\right)$$

and equation 11.4 becomes as shown in equation 11.5

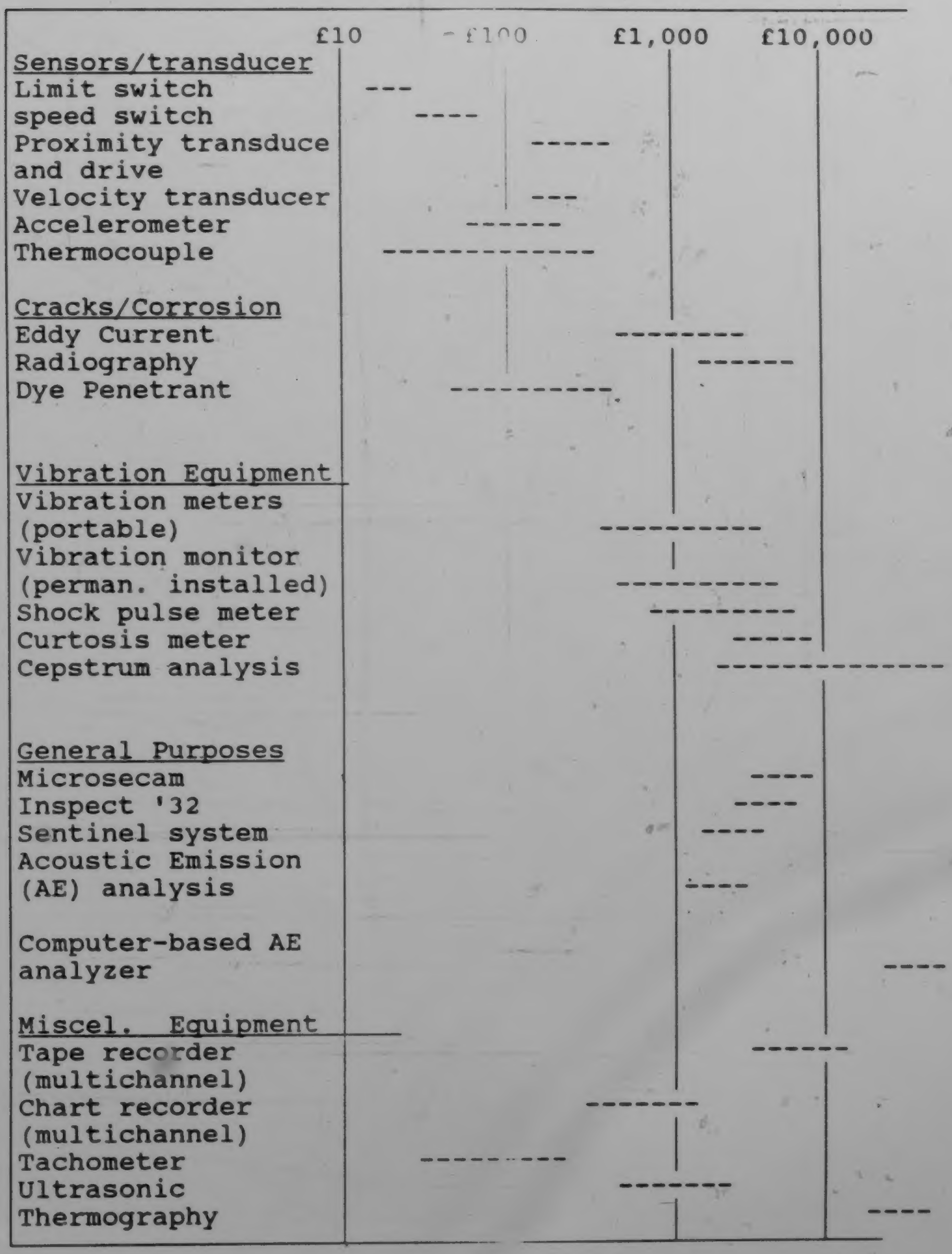
$$F(u) = \frac{1}{\sqrt{2\Pi}}\int_{-\infty}^{u}\exp-\frac{1}{2}u^{2}du \qquad 11.5$$

This is similar to putting xbar=0 and standard deviation 'σ'=1. Values of F(u) have been worked out for different values of u and tabulated on statistical tables. Hence, if x can be converted into equivalent number of standard deviations, it is possible to obtain F(x) for given values of x and thus being able to draw the Normal Distribution graphs.

11.5 Appendix 5 Condition Monitoring Devices:

Condition based maintenance is now becoming more acceptable than ever before. It was shown in chapter 6 that it is only with condition based maintenance that optimum maintenance activities can be achieved. Although no one can contend with the economical worth of condition monitoring very few companies are monitoring the condition of their equipment. It may be argued that a lot of the maintenance managers do not know the cost of condition monitoring devices. The intention of this appendix is to show the prices of some of those devices.

In Tanzania maintenance departments may buy cheaper monitoring devices, and maintenance consultant companies may buy more expensive ones. The consultant companies may then offer monitoring services at a reasonable cost. In Canada, the Alberta Motor Association (AMA) offers its customers spectrometric oil analysis at a cost of only $15 per test [105]. This is affordable to almost every car owner even in Tanzania. Table 10-4 shows some of the typical prices of condition monitoring devices. The table is annexed from P. Mahadevan and J. Sadler's article [106].

Table 10-3 Prices of Condition Monitoring Devices